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Part II

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**ADVANCED PROPELLANT STAGED COMBUSTION
FEASIBILITY PROGRAM**

Part II. Appendixes

R. E. Anderson
Aerojet-General Corporation

Technical Report AFRPL-TR-66-6, Part II
Phase I Final Report

April 1966

Prepared for
AIR FORCE ROCKET PROPULSION LABORATORY
Air Force Systems Command
Research and Technology Division
United States Air Force
Edwards Air Force Base, California

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FEASIBILITY PROGRAM

Part II. Appendixes

R. L. Anderson

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[REDACTED]

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APPENDIX I

PHYSICAL PROPERTIES OF HYDROGEN PEROXIDE

A. GENERAL IDENTIFICATION

1. Molecular Formula

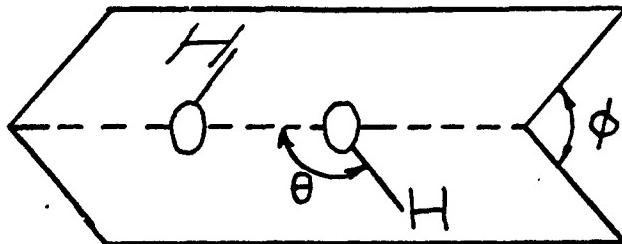


2. Molecular Weight

34.016

3. Structure and Molecular Parameters

The most widely accepted structure of hydrogen peroxide is given below,



and is designated as a skew chain. The most probable molecular dimensions in the vapor state are as follows:(1)

Bond Lengths, Å

OH 0.97 ± 0.005

OO 1.49 ± 0.01

Bond Angles, degrees

ϕ 95 ± 10

θ 100

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4. Freezing (Melting) Points

a. Anhydrous Hydrogen Peroxide

The freezing (melting) points of anhydrous hydrogen peroxide have been reported by a number of investigators and most of the values given agree very closely as shown in the following table.

Temperature			Percent Melted	Ref.
°F	°C	°K		
31.262	-0.41	272.75	not given	2, as quoted in Ref. 3
31.226	-0.43	272.72	not given	4, as quoted in Ref. 3
31.217	-0.435	272.725	100	2, as quoted in Ref. 5
31.217	-0.435	272.725	98.8	2, as quoted in Ref. 5
31.197	-0.446	272.714	65.2	2, as quoted in Ref. 5
31.186	-0.452	272.708	49.9	2, as quoted in Ref. 5
31.170	-0.461	272.699	not given	6, as quoted in Ref. 3

Schumb, et al.⁽¹⁾ recommend a value of -0.43°C (31.226°F).

b. Freezing Points of the Hydrogen Peroxide-Water System

The data of Schumb, et al.,⁽¹⁾ given below are believed to be the most reliable, but similar data are given by Foley⁽⁶⁾, Giguere⁽⁷⁾, Kubaschewski⁽⁸⁾ and Maass⁽⁹⁾. It should be noted that hydrogen peroxide solutions have a very marked tendency to supercool. This tendency is discussed in detail by Schumb, et al.⁽¹⁾

Wt% H ₂ O ₂	Temperature °F	Temperature °C	Wt% H ₂ O ₂	Temperature °F	Temperature °C
100*	31.23	-0.43	48.6	-61.6	-52.0 Compound
98**	27.5	-2.5	45.2	-62.0	-52.2 Eutectic
95	21.9	-5.6	45	-61.1	-51.7
90	11.3	-11.5	40	-42.5	-41.4
85	-0.2	-17.9	35	-27.4	-33.0
80	-12.6	-24.8	30	-14.3	-25.7
75	-26.1	-32.3	25	-3.1	-19.5
70	-40.5	-40.3	20	+5.7	-14.6
65	-56.2	-49.0	15	13.5	-10.3
61.2	-69.0	-56.1 Eutectic	10	20.5	-6.4
60	-67.9	-55.5	5	26.8	-2.9
55	-63.9	-53.3	0	32.0	0.0
50	-62.0	-52.2			

* See the preceding section for freezing points of anhydrous hydrogen peroxide.
 **The value cited was obtained from a graphical interpolation of Schumb's data.⁽¹⁾

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c. Freezing Points of Various Hydrogen Peroxide Systems

The freezing points and/or solubilities of a relatively large number of systems containing hydrogen peroxide have been reported. The large volume of data involved and the low order of importance of these data to the evaluation of high-strength hydrogen peroxide, however, precludes presentation here. Reference to these data are, however, given in the following table:

<u>Solute</u>	<u>Ref.</u>	<u>Solute</u>	<u>Ref.</u>
Acetic acid	10	Oxalic acid	13
Ammonia	11	Petroleum ether (pentane, hexane)	20
Ammonium nitrate	12	Piperidine	15
Ammonium sulfate	13	Potassium and sodium chlorate	18
Barium pyrophosphate	14	Potassium and sodium phosphates	14, 21, 22
n-Butylamine	15	Potassium chloride	13, 15, 18, 19, 23, 24
t-Butylamine	15	Potassium nitrate	13, 18, 19, 23, 24
Diethyl or dimethyl phthalate	16	Potassium peroxyulfate	25
Diethylamine	15	Potassium sulfate	15, 18, 19, 24, 25
Diethylene glycol	17	Sodium carbonate	22
Di-iso-butylamine	15	Sodium chloride	11, 18, 19
Dimethylaniline	15	Sodium fluoride	15, 18, 19
Ethyl ether	15	Sodium nitrate	11, 18, 19, 23, 26
Lead nitrate	18	Sodium sulfate	11, 14, 19
Lithium nitrate	19	Sucrose (sugar)	11
Lithium sulfate	19	Sulfuric acid (sulfur dioxide)	10, 13, 15, 25
Methyl alcohol	15	Tripropylamine	15
Methyl methacrylate	16		

5. Boiling Points of the Hydrogen Peroxide-Water System

The most reliable boiling points of hydrogen-peroxide solutions have been obtained by interpolation of vapor pressure-composition curves for various temperatures.(1),(27) These values are given in the following table and are valid as long as no decomposition occurs upon boiling. It should be noted however, that at all concentrations, some evolution of oxygen resulting from decomposition can be anticipated and the boiling points normally observed will be lowered to an extent dependent upon the amount of decomposition.(1)

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wt. % H_2O_2	Temperature		mole % H_2O_2	Temperature	
	°F	°C		°F	°C
100	302.4	150.2	100	302.4	150.2
98	299.2	148.4	90	293.2	145.1
90	286.2	141.2	80	283.5	139.7
80	271.0	132.8	70	273.2	134.0
70	257.8	125.4	60	262.8	128.2
60	246.2	119.0	50	252.1	122.3
50	237.0	113.9	40	242.1	116.7
40	229.3	109.6	30	232.7	111.5
30	223.3	106.3	20	224.4	106.9
20	218.5	103.6	10	217.4	103.0
10	214.7	101.5	0	212.0	100.0
0	212.0	100.0			

Note that boiling concentrated hydrogen peroxide at or above atmospheric pressure often leads to significant decomposition or an explosion; however, smooth boiling with minimal decomposition can be accomplished in very carefully cleaned containers made of noncatalytic materials(1).

6. Triple Point of Anhydrous Hydrogen Peroxide

Triple-point temperature⁽²⁾ = -0.42°C (31.24°F)

Triple-point pressure⁽¹⁾ = 0.26 mm Hg (0.005 psia)

7. Critical Properties of Hydrogen Peroxide

On the assumption that the ratios of critical temperature to normal boiling point are the same for both hydrogen peroxide and water, Scatchard, et al.(27) calculate the critical temperature of hydrogen peroxide to be 457°C (855°F). By using the vapor pressure equation they developed for hydrogen peroxide(27) they calculate the critical pressure to be 214 atm. (3146 psia). The accuracy of these estimates is unknown and experimental verification does not appear likely.

The critical properties of hydrogen peroxide-water solutions are not available; however, pseudocritical properties may often be used in their place and are normally estimated by Kay's method.(28) This method as applied to the H_2O_2 - H_2O system is given below in the form of equations:

$$T_c \text{ (°F)} = x_{H_2O}(705.6) + x_{H_2O_2}(855)$$

$$P_c \text{ (psia)} = x_{H_2O}(3207) + x_{H_2O_2}(3146)$$

where x_{H_2O} and $x_{H_2O_2}$ are the mole fraction of H_2O and H_2O_2 , respectively.

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B. PHASE PROPERTIES

1. Density of Solid Hydrogen Peroxide

a. Anhydrous Hydrogen Peroxide

Temperature		Density			Ref.
°F	°C	lb/ft ³	g/cm ³		
-4	-20	107	1.71	+0.05	1
18.59	-7.45	102.62	1.6437	-0.03	29
23.99	-4.45	102.60	1.6434	-0.03	29

The first value is recommended by Schumb, et al.(1) at all temperatures on the basis of their study and recalculation of X-ray diffraction data of Abrahams, et al.(30)

b. Solid Hydrogen Peroxide-Water Solutions

True solid solutions do not form according to Schumb, et al.(1) but, rather, form a solid phase with occluded mother liquor. Thus, densities depend upon the amounts of solid-phase and occluded mother liquor. In spite of the difficulties involved in defining densities of such systems, Giguère and Geoffrion(31) clearly showed that solutions containing less than 45 wt% H₂O₂ expand upon freezing whereas solutions containing more than 65 wt% H₂O₂ contract upon freezing.

2. Density of Liquid Hydrogen Peroxide

The density of the H₂O₂-H₂O system has been measured by a number of investigators over the entire range of compositions and to temperatures of approximately 200°F for all compositions except those of 90 wt% H₂O₂ or greater. Of the large amount of data available, that given in References 31, 32, 33, and 34 are generally recommended. These data have been reduced to convenient equations, tables, and figures in References 1 and 35. Because of the magnitude of this information, its easy accessibility, and its limited usefulness to the evaluation of high-strength hydrogen peroxide, these many representations are not repeated here. Attention has been focused, rather, upon compiling the density data of only 90 and 98 wt% H₂O₂ over a wide range of conditions.

The density of liquid 90 wt% H₂O₂ is given in the table below and shown graphically in Figure 1.

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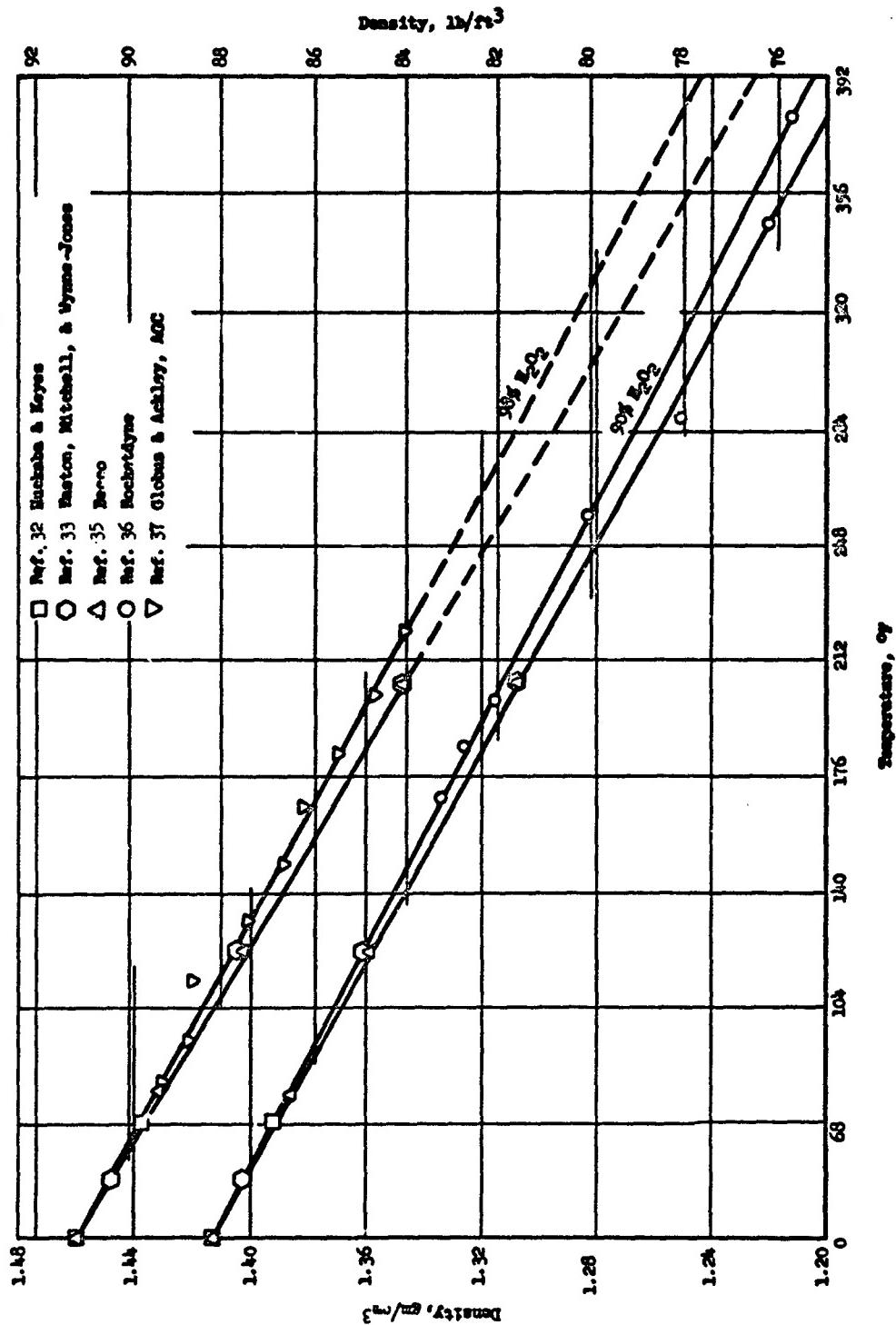


Figure 1. Density of 90 and 98% H_2O_2 (u)

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(c) Density of Liquid 90 wt% H₂O₂

Temperature °F	Temperature °C	Density		Ref.
		lb/ft ³	g/cm ³	
32	0	88.25	1.4136	32, 35
50	10	87.56	1.4026	33
68	20	86.97	1.3919	32
77	25	86.57	1.3867	33
77	25	86.57	1.3866	35
122	50	84.94	1.3605	33
122	50	84.89	1.3597	35
169.7	76.5	83.28	1.334	35 *
185.4	85.2	82.72	1.325	35 *
199.8	93.2	82.10	1.315	36 *
204.8	96	81.60	1.307	33, 35
253.3	125.7	80.10	1.283	35 *
288.5	142.5	78.10	1.251	36 *
347.0	175.0	76.16	1.220	36 *
379.4	193.0	75.66	1.212	36 *

*Averaged reported values were corrected to 90% H₂O₂ concentration because of slight thermal decomposition and/or low initial concentration.

(u) The density of liquid 98 wt% H₂O₂ is given in the table below and shown graphically in Figure 1.

Density of Liquid 98 wt% H₂O₂

Temperature °F	Temperature °C	Density		Ref.
		lb/ft ³	g/cm ³	
32	0	91.11	1.4594	32, 35
50	10	90.38	1.4477	33
68	20	89.74	1.4374	32 *
77	25	89.34	1.4311	33
77	25	89.33	1.4309	35
80.6	27	89.24	1.4294	37
93.2	34	88.73	1.4213	37
113	45	88.63	1.4195	37
122	50	87.64	1.4038	33
122	50	87.55	1.4024	35

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Temperature °F	Temperature °C	Density		Ref.
		lb/ft ³	g/cm ³	
131	55	87.42	1.4003	37
149	65	86.70	1.3988	37
167	75	86.23	1.3913	37
183.2	84	85.48	1.3693	37
201.2	94	84.68	1.3564	37
204.8	96	84.09	1.347	37
221	105	84.03	1.3460	33, 35 *
				37

*Extrapolated value

3. Density of Hydrogen-Peroxide Vapor

The use of the ideal gas law is recommended for deriving vapor densities at ordinary temperatures and pressures (1)(35). The validity of this approach has been confirmed by Matheson and Mass (15) at the conditions of their experiment, 92°C (197.6°F) and 35 mm Hg (0.63 psia).

For non-ideal regions the density may be estimated by utilizing generalized compressibility factors. (38) For more precise values, it is recommended that the compressibility factors of water be calculated from the data in Ref. 39 and applied to hydrogen peroxide by means of the theory of corresponding states.

4. Vapor Pressure of High-Strength Hydrogen Peroxide-Water Solutions

A relatively large amount of vapor-pressure data for various $H_2O_2-H_2O$ solutions is available and these data are discussed at length in Ref. 1. From considerable study of these data the authors of Ref. 1 recommend that the data of Scatchard, et al. (27) be utilized. Using the vapor pressure equation for hydrogen peroxide, the activity coefficient equations for hydrogen peroxide and water given by Scatchard, et al. and the vapor pressure data for water given by Keenan and Keyes (39), the total vapor pressures and partial pressures of H_2O_2 and H_2O over 90, 92, 94, 96, 98, and 100 wt% H_2O_2 have been calculated. The equations utilized are given below and the calculated values are presented in Tables I and II.

$$\log p_h \text{ (mm)} = 44.5760 - 4025.3/T - 12.996 \log T + 4.6055 \times 10^{-3}T \quad (1)$$

$$\ln \gamma_h = \frac{x_w^2}{RT} \left[B_0 + B_1 (3-4x_w) + B_2 (1-2x_w) (5-6x_w) \right] \quad (2)$$

$$\ln \gamma_w = \frac{(1-x_w)^2}{RT} \left[B_0 + B_1 (1-4x_w) + B_2 (1-2x_w) (1-6x_w) \right] \quad (3)$$

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Report APRIL-TR-66-6, Appendix I

TABLE I

TOTAL VAPOR PRESSURE (PSIA) OF HIGH STOICHIOMETRIC $\text{H}_2\text{C}_2\text{-H}_2\text{O}$ SYSTEMS

Temp., °F	Total Vapor Pressure in the Liquid					
	.90	.92	.94	.96	.98	100
40	.0148	.0131	.0116	.0102	.0099	.0077
60	.0342	.0306	.0272	.0242	.0213	.0183
80	.0736	.0654	.0597	.0535	.0473	.0425
100	.1493	.1357	.1229	.1111	.1001	.0899
120	.2672	.2426	.2205	.2000	.1879	.1762
140	.5255	.4834	.4436	.4063	.3714	.3383
150	.5213	.8516	.7833	.7233	.6656	.6108
160	1.553	1.442	1.337	1.237	1.144	1.055
200	2.525	2.355	2.193	2.039	1.893	1.755
220	3.977	3.722	3.479	3.248	3.023	2.818
240	6.034	5.713	5.353	5.019	4.691	4.337
260	9.061	8.535	8.030	7.546	7.033	6.639
280	13.17	12.44	11.74	11.06	10.41	9.790
300	18.73	17.74	16.78	15.85	14.95	14.10
320	26.10	24.77	23.49	22.24	21.04	19.83
340	35.71	33.95	32.26	30.62	29.03	27.48
360	48.02	45.75	43.55	41.42	39.34	37.32
380	63.57	60.63	57.87	55.12	52.45	49.84
400	82.36	79.31	75.76	72.23	68.89	65.56
420	106.8	102.3	97.84	93.50	89.23	85.04
440	135.9	130.3	124.8	119.4	114.1	103.9
460	170.9	164.1	157.4	150.7	144.2	137.8
480	212.7	204.4	196.3	188.3	180.3	172.4
500	262.2	252.2	242.4	232.8	223.2	213.6
520	320.2	303.4	286.7	269.1	273.6	262.1
540	387.9	373.9	350.0	336.3	332.6	318.9
560	465.3	442.8	423.4	417.2	401.0	384.7
580	556.4	537.1	518.0	499.9	473.8	450.7
600	659.5	637.1	614.8	592.5	570.2	547.7
620	776.9	751.0	725.1	699.2	673.1	646.9
640	910.1	880.1	850.2	810.1	780.9	750.4
660	1060	1026	991.4	956.7	921.8	885.3
680	1230	1190	1150	1110	1070	1029
700	1420	1375	1329	1283	1236	1189
720	1631	1579	1527	1474	1421	1367
740	1863	1809	1749	1689	1627	1564
760	2131	2054	1985	1906	1855	1783
780	2402	2345	2267	2183	2103	2025
800	2743	2656	2567	2477	2386	2291
820	3094	2996	2896	2794	2690	2583
840				3143	3025	2904
855						3146

Report AFREL-TR-66-6, Appendix I

TABLE II

PARTIAL PRESSURES (PSIA) OF H₂O₂ AND H₂O ABOVE HIGH STRENGTH H₂O₂-H₂O SOLUTIONS

Temp., °P	90 wt% H ₂ O ₂		92 wt% H ₂ O ₂		94 wt% H ₂ O ₂		96 wt% H ₂ O ₂		98 wt% H ₂ O ₂	
	p _{H₂O₂}	p _{H₂O}								
40	0.0062	0.0086	0.0065	0.0066	0.0068	0.0048	0.0071	0.0031	0.0074	0.0015
60	0.0151	0.0191	0.0153	0.0147	0.0166	0.0107	0.0173	0.0068	0.0181	0.0033
80	0.0342	0.0394	0.0359	0.0305	0.0376	0.0221	0.0392	0.0143	0.0409	0.0069
100	0.0726	0.0768	0.0760	0.0596	0.0795	0.0434	0.0830	0.0281	0.0865	0.0136
120	0.1449	0.1423	0.1517	0.1108	0.1587	0.0809	0.1655	0.0524	0.1724	0.0255
140	0.2742	0.2513	0.2871	0.1952	0.3001	0.1435	0.3130	0.0933	0.3260	0.0455
160	0.4949	0.4264	0.5180	0.3336	0.5413	0.2446	0.5645	0.1593	0.5877	0.0779
180	0.8560	0.6966	0.8957	0.5462	0.9355	0.4013	0.9755	0.2620	1.015	0.1283
200	1.425	1.101	1.490	0.8646	1.556	0.6365	1.622	0.4165	1.688	0.2044
220	2.291	1.687	2.395	1.327	2.500	0.9790	2.606	0.6118	2.712	0.3157
240	3.569	2.515	3.731	1.982	3.893	1.465	4.057	0.9620	4.222	0.4740
260	5.405	3.656	5.648	2.887	5.893	2.137	6.140	1.406	6.389	0.6939
280	7.977	5.196	8.333	4.109	8.693	3.046	9.056	2.007	9.422	0.9225
300	11.50	7.233	12.01	5.728	12.53	4.252	13.05	2.807	13.57	1.350
320	16.22	9.880	16.94	7.835	17.66	5.825	18.39	3.850	19.13	1.910
340	22.44	13.26	23.43	10.53	24.42	7.840	25.43	5.190	26.45	2.578
360	30.49	17.52	31.82	13.93	33.17	10.39	34.53	6.804	35.92	3.424
380	40.75	22.82	42.52	18.16	44.31	13.56	46.13	8.997	47.97	4.402
400	53.63	29.32	55.95	23.37	58.30	17.46	60.63	11.60	63.10	5.763
420	69.61	37.22	72.60	29.69	75.64	22.21	78.72	14.77	81.85	7.377
440	89.19	46.70	93.00	37.29	96.88	27.83	100.8	18.60	104.8	9.253
460	112.9	58.00	117.7	46.36	122.6	34.75	127.6	23.17	132.6	11.59
480	141.4	71.33	147.4	57.06	153.5	42.82	159.7	28.58	166.0	14.32
500	175.2	86.95	182.6	69.63	190.2	52.29	197.8	34.93	205.6	17.52
520	215.1	105.1	224.1	84.25	233.4	63.33	242.8	42.35	252.4	21.26
540	261.8	126.1	272.8	101.2	283.9	76.11	295.3	50.94	307.0	25.59
560	316.0	150.3	329.2	121.6	342.6	90.83	356.3	63.84	370.4	30.60
580	378.5	177.9	394.2	142.9	410.3	107.7	426.7	72.19	443.5	36.33
600	450.2	209.3	468.8	168.3	487.9	126.9	507.4	85.15	527.3	42.69
610	524.7	285.4	650.4	229.7	676.7	173.5	703.6	116.6	731.1	50.62
630	617.0	382.6	881.7	308.4	917.1	233.3	953.4	157.0	990.7	79.30
650	720	505.1	1171	407.6	1218	308.7	1266	208.0	1316	105.2
670	1470	661.6	1529	534.5	1653	273.4	2124	353.9	1716	133.5
690	1889	853.7	1965	690.5	2043	524.0	2590	667.7	2206	179.5
710	2396	1085	2492	878.8	2692	451.4			2796	229.2

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$$P(\text{tot}) = p_h (1-x_w) \gamma_h + p_w x_w \gamma_w \quad (4)$$

$$p_{p_h} = p_h (1-x_w) \gamma_h \quad (5)$$

$$p_{p_w} = p_w x_w \gamma_w \quad (6)$$

where p_h and p_w are the vapor pressures of hydrogen peroxide and water, respectively; γ_h and γ_w are the activity coefficients of peroxide and water, respectively; P is total pressure; p_{p_h} and p_{p_w} are the partial pressures of hydrogen peroxide and water, respectively; T is temperature in °K; x_w is the mole fraction of water in the liquid phase; R is the gas constant, 1.987 cal/g mole °C; $B_0 = -1017 + 0.97 T$; $B_1 = 85$; and B_2 is 13.

5. Activity Coefficients of High Strength Hydrogen Peroxide-Water Solutions

The activity coefficients of 90, 92, 94, 96, 98, and 100 wt% H_2O_2 have been calculated from the equations of Scatchard, et al. (2) - see preceding section, Equations (2) and (3). These data are given in Table III.

6. Vapor-Liquid Equilibrium Data for High Strength Hydrogen Peroxide-Water Solutions

On the basis of the vapor pressure and activity coefficient equations and data given in Sections B, 4 and 5, and composition of the vapor in equilibrium with liquid 90, 92, 94, 96, and 98 wt% $H_2O_2-H_2O$ solutions has been calculated according to the following equation:

$$y_h = \frac{p_h x_h \gamma_h}{P}$$

where y_h is the mole fraction of H_2O_2 in the vapor phase, x_h is the mole fraction of H_2O_2 in the liquid phase, p_h is the vapor pressure of H_2O_2 , γ_h is the activity coefficient of H_2O_2 , and P is the total vapor pressure.

These composition data are given in Table IV.

7. Solubility of Hydrogen Peroxide in Various Substances

<u>Substance</u>	<u>Solubility</u>	<u>Ref.</u>
Allymer CR-39 monomer	28g (90 wt% H_2O_2)/100g	40
Amyl alcohol	Greater than that of water in the amyl alcohol	1
Aniline	90 wt% H_2O_2 is infinitely soluble.	40

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TABLE III
ACTIVITY COEFFICIENTS OF THE HIGH STRENGTH H₂O₂-H₂O SYSTEM

Temp., °F.	90 wt% H ₂ O ₂		92 wt% H ₂ O ₂		94 wt% H ₂ O ₂		96 wt% H ₂ O ₂		98 wt% H ₂ O ₂		100 wt% H ₂ O ₂	
	γ_h	γ_w	γ_h	γ_w								
40	.9722	.4089	.9821	.3872	.9899	.3662	.9959	.3459	.9989	.3265	1.000	.3079
60	.9738	.4286	.9831	.4072	.9916	.3864	.9958	.3662	.9990	.3468	1.000	.3233
80	.9766	.4664	.9850	.4456	.9921	.4252	.9963	.4051	.9991	.3864	1.000	.3011
100	.9779	.4844	.9858	.4639	.9921	.4439	.9965	.4241	.9991	.4055	1.000	.3075
120	.9791	.5018	.9866	.4817	.9925	.4620	.9967	.4428	.9992	.4243	1.000	.4055
140	.9803	.5186	.9874	.4989	.9929	.4796	.9969	.4608	.9992	.4426	1.000	.4252
160	.9813	.5349	.9881	.5157	.9933	.4968	.9971	.4784	.9993	.4605	1.000	.4344
180	.9823	.5507	.9887	.5319	.9937	.5135	.9972	.4954	.9993	.4780	1.000	.4524
200	.9833	.5660	.9893	.5477	.9940	.5297	.9974	.5121	.9994	.4950	1.000	.4737
220	.9842	.5815	.9899	.5629	.9944	.5454	.9975	.5283	.9994	.5117	1.000	.4953
240	.9850	.5951	.9905	.5778	.9947	.5607	.9977	.5440	.9994	.5279	1.000	.5124
260	.9858	.6090	.9910	.5921	.9950	.5755	.9978	.5594	.9995	.5437	1.000	.5267
280	.9865	.6224	.9915	.6061	.9953	.5900	.9979	.5743	.9995	.5591	1.000	.5416
300	.9873	.6355	.9919	.6195	.9955	.6040	.9981	.5883	.9995	.5741	1.000	.5501
320	.9879	.6481	.9824	.6327	.9958	.6177	.9982	.6030	.9994	.5803	1.000	.5553
340	.9886	.6603	.9828	.6455	.9960	.6309	.9983	.6167	.9995	.6031	1.000	.5604
360	.9890	.6722	.9932	.6579	.9962	.6138	.9984	.6301	.9995	.6170	1.000	.5653
380	.9892	.6837	.9936	.6699	.9964	.6564	.9985	.6432	.9995	.6306	1.000	.5703
400	.9898	.6949	.9939	.6816	.9967	.6636	.9986	.6559	.9995	.6433	1.000	.5753
420	.9904	.7058	.9943	.6930	.9969	.6804	.9987	.6633	.9995	.6557	1.000	.5804
440	.9909	.7163	.9946	.7040	.9971	.6920	.9987	.6804	.9997	.6693	1.000	.5854
460	.9914	.7266	.9949	.7147	.9972	.7032	.9988	.6921	.9997	.6816	1.000	.5904
480	.9919	.7365	.9952	.7252	.9974	.7141	.9991	.7035	.9997	.6936	1.000	.5953
500	.9924	.7462	.9955	.7354	.9976	.7248	.9992	.7147	.9998	.7052	1.000	.6004
520	.9928	.7562	.9958	.7452	.9977	.7352	.9991	.7256	.9998	.7165	1.000	.6053
540	.9932	.7556	.9961	.7549	.9979	.7453	.9991	.7362	.9998	.7278	1.000	.6102
560	.9937	.7668	.9964	.7651	.9981	.7552	.9992	.7466	.9998	.7386	1.000	.6151
580	.9941	.7737	.9964	.7734	.9982	.7648	.9993	.7567	.9998	.7493	1.000	.6201
600	.9945	.7823	.9966	.7823	.9983	.7734	.9993	.7661	.9999	.7607	1.000	.6250
620	.9952	.7920	.9971	.7909	.9985	.7833	.9994	.7761	.9999	.7728	1.000	.6300
640	.9957	.8018	.9975	.8076	.9987	.8009	.9995	.7861	.9999	.7847	1.000	.6350
660	.9961	.8055	.9975	.8235	.9990	.8176	.9996	.8124	.9996	.8079	1.000	.6400
720	.9971	.8441	.9983	.8386	.9992	.8336	.9997	.8293	.9999	.8258	1.000	.6450
760	.9977	.8577	.9987	.8530	.9990	.8498	.9998	.8451	.9998	.8420	1.000	.6500
800	.9982	.8706	.9990	.8667	.9996	.8654	.9999	.8608	.9999	.8592	1.000	.6557

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TABLE IV

VAPOR COMPOSITION (MOLE FRACTION H₂O₂) OVER HIGH-STRENGTH H₂O₂-H₂O SOLUTIONS

Temp., °F.	Liquid-Phase Composition, wt% H ₂ O ₂ (mole fraction H ₂ O ₂)				
	90 (0.8266)	92 (0.8590)	94 (0.8924)	96 (0.9271)	98 (0.9629)
40	0.4171	0.4938	0.5862	0.6979	0.8337
60	0.4423	0.5184	0.6090	0.7168	0.8455
80	0.4652	0.5407	0.6292	0.7332	0.8555
100	0.4859	0.5604	0.6469	0.7473	0.8640
120	0.5044	0.5779	0.6623	0.7594	0.8712
140	0.5218	0.5940	0.6764	0.7704	0.8776
160	0.5372	0.6083	0.6883	0.7799	0.8830
180	0.5513	0.6212	0.6998	0.7883	0.8878
200	0.5642	0.6328	0.7097	0.7957	0.8920
220	0.5759	0.6434	0.7186	0.8024	0.8957
240	0.5867	0.6530	0.7266	0.8084	0.8991
260	0.5965	0.6618	0.7339	0.8137	0.9020
280	0.6056	0.6698	0.7405	0.8186	0.9047
300	0.6139	0.6771	0.7465	0.8230	0.9071
320	0.6215	0.6838	0.7520	0.8269	0.9092
340	0.6286	0.6899	0.7570	0.8305	0.9112
360	0.6350	0.6955	0.7616	0.8338	0.9130
380	0.6410	0.7007	0.7657	0.8368	0.9146
400	0.6465	0.7054	0.7695	0.8395	0.9160
420	0.6516	0.7098	0.7730	0.8420	0.9173
440	0.6563	0.7138	0.7762	0.8442	0.9185
460	0.6607	0.7175	0.7792	0.8463	0.9196
480	0.6647	0.7209	0.7819	0.8482	0.9206
500	0.6684	0.7240	0.7843	0.8499	0.9215
520	0.6717	0.7268	0.7866	0.8515	0.9223
540	0.6749	0.7295	0.7886	0.8529	0.9230
560	0.6777	0.7318	0.7904	0.8542	0.9237
580	0.6803	0.7340	0.7921	0.8553	0.9243
600	0.6826	0.7359	0.7936	0.8563	0.9248
640	0.6864	0.7390	0.7959	0.8578	0.9255
680	0.6883	0.7408	0.7972	0.8586	0.9259
720	0.6903	0.7418	0.7979	0.8589	0.9260
760	0.6896	0.7410	0.7969	0.8581	0.9254
800	0.6888	0.7400	0.7959	0.8572	0.9248
840	---	---	---	0.8564	0.9242

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<u>Substance</u>	<u>Solubility</u>	<u>Ref.</u>
Benzene	Practically insoluble	1, 11
Carbon tetrachloride	Less than 0.1% soluble	41
Chloroform	Less than 0.1% soluble	41
Diethyl phthalate	2.5g (90 wt% H ₂ O ₂)/100g	40
Dimethyl phthalate	28g (90 wt% H ₂ O ₂)/100g	40
Ethyl acetate	90 wt% H ₂ O ₂ is infinitely soluble	40
Ethyl alcohol	88 to 99.6 wt% H ₂ O ₂ is completely miscible with equal volumes of absolute alcohol at 32°F	11
Ethyl ether	H ₂ O ₂ and ether form non-ideal solutions with complete miscibility only above 176°F	1
Kerosene	Less than 0.1% soluble	41
Methyl methacrylate	18g (90 wt% H ₂ O ₂)/100g	40
Quinoline	Greater than that of water in quinoline	1
Styrene	Less than 0.1% soluble	41
Toluene	Less than 0.1% soluble	41
Water	Completely miscible	11

See also Section A, 4, c for references to freezing point and/or solubility data for other hydrogen peroxide systems.

8. Surface Tension of the Hydrogen Peroxide-Water System

The surface tension of hydrogen peroxide-water solutions has been measured by Spring⁽⁴²⁾, Maass and Hatcher⁽²⁹⁾ and Phibbs and Giguère⁽⁴³⁾. After studying these data Schumb, et al.⁽¹⁾ recommend the values of Phibbs and Giguère. These values are given in the following table:

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Wt% H ₂ O ₂	Surface Tension			
	lb/ft x 10 ³ 32°F (0°C)	lb/ft x 10 ³ 68°F (20°C)	dynes/cm 32°F (0°C)	dynes/cm 68°F (20°C)
0.00	5.184	4.985	75.65	72.75
17.05	5.232	5.030	76.36	73.41
26.31	5.273	5.079	76.95	74.12
37.33	5.324	5.117	77.69	74.67
49.76	5.373	5.186	78.41	75.68
64.33	5.456	5.252	79.62	76.65
71.55	5.515	5.301	80.48	77.36
84.12	5.613	5.387	81.92	78.61
90.00*	5.633	5.434	82.2	79.3
95.75	5.683	5.473	82.93	79.87
98.00**	5.694	5.496	83.1	80.2
100.00**	5.71	5.51	83.3	80.4

*Interpolated value

**Extrapolated value, precision: ± 0.05 dyne/cm

C. THERMODYNAMIC PROPERTIES

1. Heat and Entropy of Fusion

The recommended values for the heat and entropy of fusion of anhydrous hydrogen peroxide are those of Giguère et al. (2)

$$\Delta H_{fus} = 158.1 \text{ Btu/lb} = 87.84 \text{ cal/g} = 2987 \pm 3 \text{ cal/g mole}$$

$$\Delta S_{fus} = 0.3219 \text{ Btu/lb-°R or cal/g-°K} = 10.95 \pm 0.01 \text{ cal/g mole-°K}$$

2. Heat and Entropy of Vaporization

a. Heat of Vaporization of Anhydrous Hydrogen Peroxide

Many values for the heat of vaporization have been published, but only those of Foley and Giguère (4) and Giguère et al. (44) are based on direct measurements. These measurements are generally conceded to be far more precise than values calculated from even the most precise vapor pressure data. Ecco (35) recommends the values given in the following table which they calculated based upon the data from Ref. 44 and supplementary data from Ref. 2.

Heat of Vaporization of Anhydrous Hydrogen Peroxide

<u>Temperature</u> °F	<u>Temperature</u> °C	<u>Heat of Vaporization</u>		
		<u>Btu/lb</u>	<u>cal/g</u>	<u>cal/g-mole</u>
32	0	666.5	370.3	12600
77	25	652.7	362.6	12330
80.4	26.9	651.9	362.0	12310
122	50	639.2	355.1	12080
212	100	612.0	340.0	11560
302	150	584.5	324.7	11040

b. Heat of Vaporization of Hydrogen Peroxide-Water Solutions

The heat of vaporization of H₂O₂-H₂O solutions at 77°F and the normal boiling points have been calculated by Ecco(35) from the heat of vaporization of anhydrous H₂O₂ given in the previous section, the heat of vaporization of water given by Rossini et al.(45), and the heat of dilution given by Giguère et al.(44). These values are presented in the following table.

Total Heat of Vaporization of Hydrogen Peroxide-Water Solutions

Composition, Wt% H ₂ O ₂	<u>Total Heat of Vaporization</u>			
	<u>77°F (25°C)</u>	<u>Normal Boiling Point</u>	<u>Btu/lb</u>	<u>cal/g</u>
100	652.7	362.6	584.5	324.7
98	662.2	367.9	593	329
90	700.4	389.1	630	350
80	745.2	414.0	675	375
70	788.2	437.9	718	399
60	329.3	460.7	759	422
50	868.5	482.5	798	443
40	906.5	503.6	835	464
30	943.2	524.0	870	483
20	979.4	544.1	905	503
10	1015.0	563.9	938	521
0	1050.5	583.6	970	539

c. Entropy of Vaporization

The entropy of vaporization can be calculated from the heat of vaporization data presented in the two preceding sections and the equation given below.

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$$\Delta S_{vap} = \Delta H_{vap}/T$$

where T is absolute temperature.

3. Heat of Sublimation of Anhydrous Hydrogen Peroxide

The heat of sublimation at 31.170°F (-0.461°C) is given by Foley and Giguère⁽⁶⁾.

$$\Delta H_{sub} = 820.7 \text{ Btu/lb} = 455.9 \text{ cal/g} = 15510 \text{ cal/g-mole}$$

4. Heats of Solution and Dilution

The most valid heat of solution and dilution data are based upon the work of Giguère et al.⁽⁴⁴⁾ which involved the use of an isothermal calorimeter at 26.9°C. Schumb et al.⁽¹⁾ have corrected these values to 77°F (25°C), a conventional standard state temperature. These latter data are given below.

Wt% H ₂ O ₂	Integral Heat of Solution*		Heat of Dilution**	
	Btu/lb H ₂ O ₂	cal/mole H ₂ O ₂	Btu/lb H ₂ O ₂	cal/mole H ₂ O ₂
100	0	0	-43.0	-813
98	-1.7	-32	-41.3	-781
90	-8.5	-160	-34.6	-653
80	-16.4	-310	-26.6	-503
70	-23.2	-438	-19.8	-375
60	-28.8	-545	-14.2	-268
50	-33.7	-636	-9.4	-177
40	-37.2	-703	-5.8	-110
30	-39.8	-752	-3.2	-61
20	-41.5	-785	-1.4	-27
10	-42.6	-805	-0.4	-8
0	-43.0	-813	0	0

*The integral heat of solution is defined as the enthalpy change associated with the process of mixing pure water and 100% H₂O₂ to form a solution of indicated composition (wt% H₂O₂).

**The heat of dilution is defined as the enthalpy change associated with diluting a solution of indicated composition (wt% H₂O₂) with an infinite amount of water to form an infinitely dilute solution of H₂O₂.

5. Heat of Formation of Hydrogen Peroxide

a. Anhydrous Liquid

The heat of formation of anhydrous liquid hydrogen peroxide at 77°F from the elements at 77°F according to the reaction,

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has been reported in Reference 46 to be -44.88 kcal/g-mole, in Reference 1 to be -44.85 kcal/g-mole, and in Reference 47 to be -44.75 ± 0.15 kcal/g-mole. Although the derivation of these values has not been carefully scrutinized, the first value is recommended on the basis that it is most recent and comes from a normally very reliable source.

$$\Delta H_f(77^\circ\text{F}) = -2375 \text{ Btu/lb} = -1319 \text{ cal/g} = -44.88 \text{ kcal/g-mole}$$

b. Aqueous Hydrogen Peroxide

The heat of formation of hydrogen peroxide in aqueous solution at 77°F from the elements and water at 77°F according to the reaction,



can be calculated from the value for the anhydrous liquid given in the previous section and the integral heat of solution values given in Section C,4. The values thus calculated are given in the table below.

HEAT OF FORMATION OF HYDROGEN PEROXIDE IN AQUEOUS SOLUTION AT 77°F

Soln. Comp., Wt% H ₂ O ₂	Heat of Formation, ΔH _f		
	Btu/lb H ₂ O ₂	cal/g H ₂ O ₂	kcal/g-mole H ₂ O ₂
100	-2375	-1319	-44.88
98	-2377	-1320	-44.91
90	-2383	-1324	-45.04
80	-2391	-1328	-45.19
70	-2398	-1332	-45.32
60	-2404	-1335	-45.42
50	-2409	-1338	-45.52
40	-2412	-1340	-45.53
30	-2415	-1341	-45.63
20	-2416	-1342	-45.65
10	-2417	-1343	-45.63
0	-2418	-1343	-45.69

c. Gaseous Hydrogen Peroxide

The heat of formation of gaseous hydrogen peroxide at 77°F from the elements at 77°F according to the reaction,



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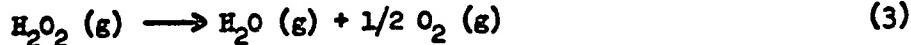
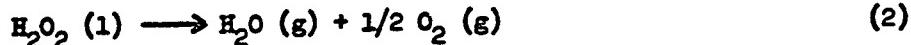
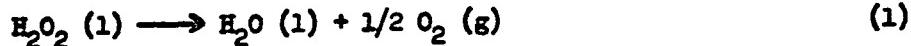
is given in Reference 46 as -32.58 kcal/g-mole and in Reference 1 as -32.52 kcal/g-mole. The former value is recommended.

$$\Delta H_f(77^\circ\text{F}) = -1724 \text{ Btu/lb} = -958 \text{ cal/g} = -32.58 \text{ kcal/g-mole}$$

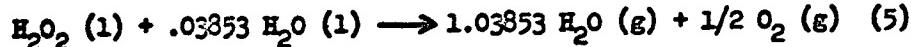
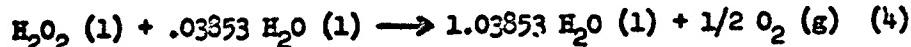
6. Heat of Decomposition of Hydrogen Peroxide

The heat of decomposition of hydrogen peroxide can be readily calculated from the heats of formation of hydrogen peroxide, water, and oxygen. Using the data for hydrogen peroxide given in Section C,5 and the water and oxygen data from Reference 45, the heat of decomposition at 77°F has been calculated for several cases as defined by the reactions below.

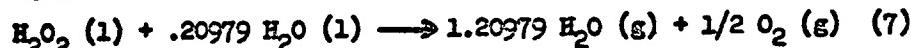
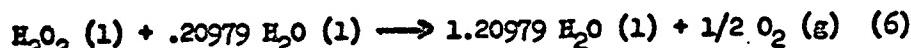
100 wt% H₂O₂:



98 wt% H₂O₂ (1):



90 wt% H₂O₂ (1):



Decomp. Reaction	Heat of Decomposition at 77°F		
	Btu/lb H ₂ O ₂	cal/g H ₂ O ₂	kcal/g-mole H ₂ O ₂
(1)	-1240	-639	-23.44
(2)	-634	-380	-12.92
(3)	-1534	-741	-25.22
(4)	-1239	-683	-23.41
(5)	-661	-357	-12.48
(6)	-1232	-684	-23.28
(7)	-558	-310	-10.55

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7. Heat of Dissociation of Hydrogen Peroxide

The heat of dissociation of gaseous hydrogen peroxide at 77°F according to the various reactions shown below have been calculated from the heat of formation of H_2O_2 (g) given in Section C,5,c and the heats of formation of the other species as given in the JANAF Thermochemical Tables(43).

Reaction	Heat of Dissociation	
	Btu/lb H_2O_2	kcal/g-mole H_2O_2
H_2O_2 (g) \longrightarrow H_2O (g) + O (g)	1817	34.34
H_2O_2 (g) \longrightarrow 2 OH (g)	2711	51.24
H_2O_2 (g) \longrightarrow HO ₂ (g) + H (g)	4750 \pm 100	89.7 \pm 2
H_2O_2 (g) \longrightarrow 2 H (g) + O ₂ (g)	7238	136.78
H_2O_2 (g) \longrightarrow H ₂ (g) + 2 O (g)	8027	151.70
H_2O_2 (g) \longrightarrow 2 H (g) + 2 O (g)	13541	255.90

8. Heat Capacity of Solid Hydrogen Peroxide

The recommended values are those of Giguère et al.(2) given below.

Temperature °F	Temperature R	Temperature K	Heat Capacity	
			Btu/lb-°F	cal/g-mole-°C
-438.1	21.6	12	0.0018	0.062
-432.7	27	15	0.0036	0.124
-423.7	36	20	0.0037	0.295
-405.7	54	30	0.0256	0.872
-387.7	72	40	0.0484	1.648
-369.7	90	50	0.0736	2.505
-351.7	108	60	0.0991	3.372
-333.7	126	70	0.1231	4.188
-315.7	144	80	0.1439	4.895
-297.7	162	90	0.1637	5.563
-279.7	180	100	0.1806	6.144
-243.7	216	120	0.2106	7.164
-207.7	252	140	0.2363	8.039
-171.7	288	160	0.2593	8.822
-135.7	324	180	0.2809	9.556
-99.7	360	200	0.3023	10.283
-63.7	396	220	0.3247	11.044
-27.7	432	240	0.3486	11.857

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(u) Temperature			(u) Heat Capacity	
$^{\circ}\text{F}$	$^{\circ}\text{K}$	$^{\circ}\text{K}$	Btu/lb- $^{\circ}\text{F}$	cal/g-mole soln.- $^{\circ}\text{C}$
8.3	469	260	0.3711*	12.624*
26.3	486	270	0.3828*	13.021*

*Corrected for premelting

9. Heat Capacity of Liquid Hydrogen Peroxide

(u) The mean heat capacities between 32 and 80.4°F (0 and 26.9°C) of various hydrogen peroxide-water solutions have been measured by Giglioli et al.(44) Smoothed values based upon their data are given in the following table.

Wt% H ₂ O ₂	Mean Heat Capacity between 32 and 80.4°F	
	Btu/lb soln.- $^{\circ}\text{F}$	cal/g-mole soln.- $^{\circ}\text{C}$
100	0.628	21.36
98	0.634	21.20
90	0.650	20.62
80	0.692	19.99
70	0.725	19.48
60	0.757	19.00
50	0.790	18.61
40	0.823	18.27
30	0.860	18.04
20	0.899	17.88
10	0.945	17.87
0	1.002	18.06

(c) Additional heat capacities of 90 wt% H₂O₂ have been measured by Rocketdyne(49) in a flow system at elevated temperatures. These values and the value from Reference 44 are given in the following table and in Figure 2.

Temperature		Heat Capacity		Reference
$^{\circ}\text{F}$	$^{\circ}\text{C}$	Btu/lb- $^{\circ}\text{F}$	cal/g-mole soln.- $^{\circ}\text{C}$	
32 to 80.4	0 to 26.9	0.660	20.62	44
235.8	113.2	0.6314	21.29	49*
304.9	151.6	0.6365	21.45	49*
369.7	187.6	0.6380	21.81	49*

*Average of 7 or 8 data points reduced from each of three separate runs made in a flow system.

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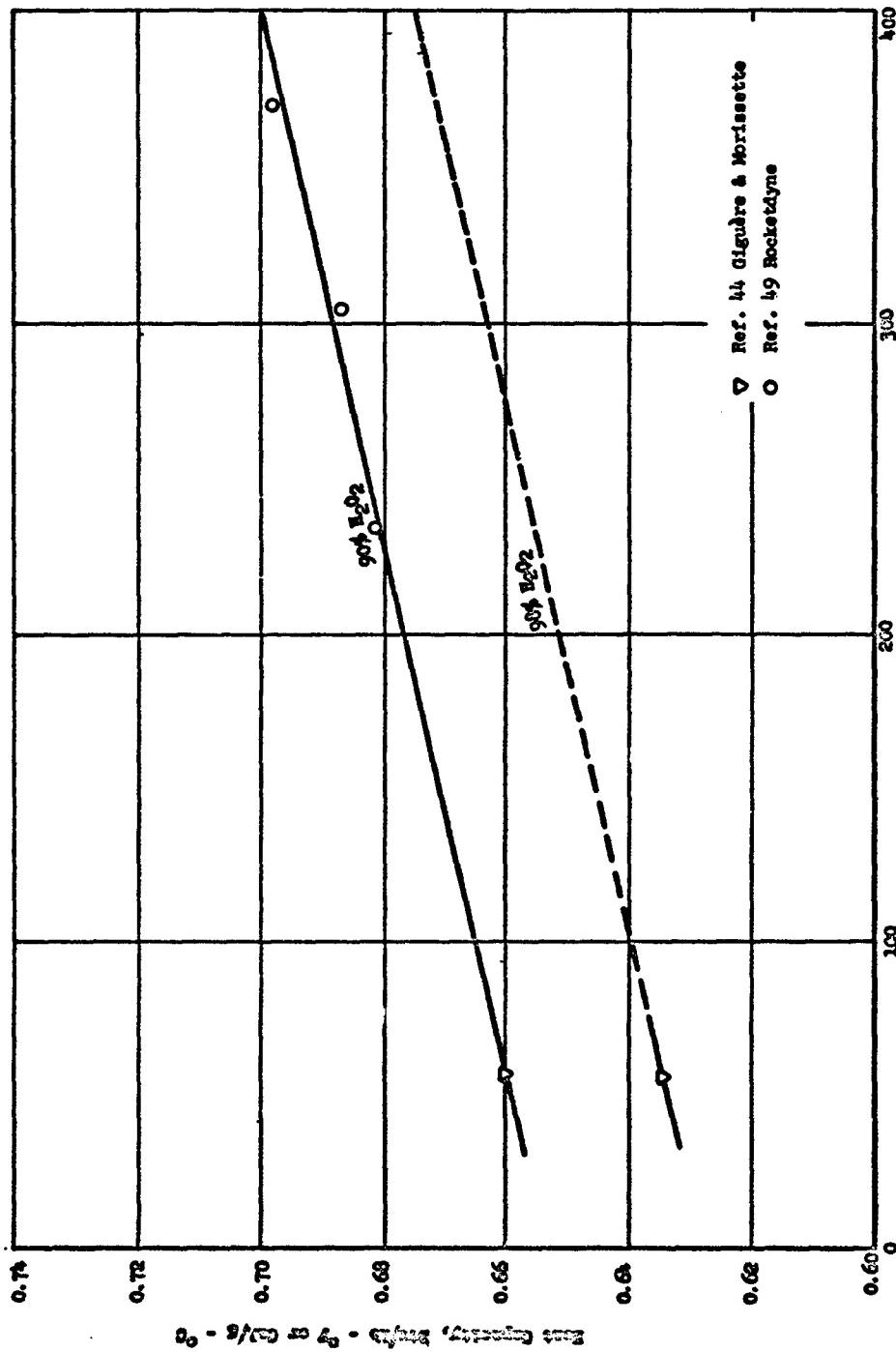


Figure 2. Heat Capacity of 90 and 98% H_2O_2 (u)

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(c) The heat capacity of 93 wt% H₂O₂ has been estimated at temperatures up to 400°F on the basis of the data from References 44 and 49 and is also shown in Figure 2.

10. Heat Capacity of Gaseous Hydrogen Peroxide

(u) The heat capacity of hydrogen peroxide vapor (as an ideal gas) has been calculated by several authors from equations developed from quantum theory. The values of Giguere and Liu⁽⁵⁰⁾ are, however, recommended. These values are given below.

Temperature °F	Temperature °K		Heat Capacity, C Btu/lb-°F		C cal/g-mole-°C
	°F	°K	°Btu/lb-°F	°cal/g-mole-°C	
77	536.7	293.16	0.3031	10.31	
80	540	300	0.3037	10.33	
170	630	350	0.3223	10.93	
260	720	400	0.3404	11.53	
440	900	500	0.3692	12.56	
620	1060	600	0.3913	13.31	
800	1260	700	0.4075	13.86	
980	1440	800	0.4204	14.30	
1160	1620	900	0.4319	14.69	
1340	1800	1000	0.4416	15.02	
1520	1980	1100	0.4507	15.33	
1700	2160	1200	0.4589	15.61	
1880	2340	1300	0.4665	15.87	
2060	2520	1400	0.4735	16.11	
2240	2700	1500	0.4801	16.33	

11. Entropy of Hydrogen Peroxide

a. Solid Hydrogen Peroxide

(u) The entropy of solid hydrogen peroxide has been calculated by Giguere et al.⁽²⁾ from his low-temperature heat-capacity data.

$$S_{H_2O_2(s)} \text{ at } 31.25^\circ\text{F} = 0.3916 \text{ Btu/lb-}^\circ\text{F} = 13.34 \pm 0.01 \text{ cal/g-mole-}^\circ\text{C}$$

b. Entropy of Liquid Hydrogen Peroxide

(u) The entropy of liquid hydrogen peroxide has been calculated by Giguere et al.⁽²⁾ from his values for the solid given above and the entropy of fusion given in Section C,1.

$$S_{H_2O_2(l)} \text{ at } 31.25^\circ\text{F} = 0.7135 \text{ Btu/lb-}^\circ\text{F} = 24.87 \pm 0.02 \text{ cal/g-mole-}^\circ\text{C}$$

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c. Entropy of Ideal Gaseous Hydrogen Peroxide

The entropy of ideal gaseous hydrogen peroxide at one atmosphere has been calculated by Giguère and Liu(50) from 77 to 2240°. These values are given in the following table.

Temperature			Entropy, S	
°F	R	K	Btu/lb-°F	cal/g-mole-°C
77	536.7	298.16	1.636	55.66
80	540	300	1.638	55.72
170	630	350	1.636	57.35
260	720	400	1.731	58.87
440	900	500	1.898	61.51
620	1080	600	1.879	63.91
800	1260	700	1.941	65.02
980	1440	800	1.996	67.91
1160	1620	900	2.046	69.61
1340	1800	1000	2.092	71.17
1520	1980	1100	2.135	72.62
1700	2160	1200	2.174	73.96
1880	2340	1300	2.212	75.23
2060	2520	1400	2.247	76.43
2240	2700	1500	2.279	77.53

12. Enthalpy of Ideal Gaseous Hydrogen Peroxide

The enthalpy of ideal gaseous hydrogen peroxide has been calculated by Giguère and Liu(50). These values are given in the following table.

Temperature			Enthalpy of Ideal Gas, (E _i -E ₀ 8.16)	
°F	R	K	Btu/lb	cal/g-mole
77	536.7	298.16	0	0
80	540	300	1	19
170	630	356	29	550
260	720	400	59	1120
440	900	500	123	2320
620	1080	600	192	3620
800	1260	700	264	4920
980	1440	800	339	6400
1160	1620	900	415	7850
1340	1800	1000	494	9330
1520	1980	1100	574	10850
1700	2160	1200	656	12320
1880	2340	1300	739	13770
2060	2520	1400	823	15560
2240	2700	1500	910	17190

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D. TRANSPORT PROPERTIES

1. Viscosity of Liquid Hydrogen Peroxide

(u) The most recent and apparently most reliable viscosity data available for various hydrogen peroxide-water solutions are those of Mitts and Giguere(43) and Kindron and Shanley(34). These data have been smoothed and interpolated to define the viscosity at even intervals of composition. These smoothed values are given in the table below.

Viscosity of H₂O₂-H₂O Solutions

Wt% H ₂ O ₂	composition				10/00-1000°C				Ref.
	32°F	61°F	77°F	122°F	32°F	61°F	77°F	122°F	
100**	1.824	1.248			1.226	0.839			43
100	1.796		1.156	0.819	1.207		0.777	0.550	34
98	1.839	1.252			1.236	0.841			43
98	1.812		1.156	0.816	1.218		0.777	0.548	34
90	1.887	1.260			1.263	0.847			43
90	1.872		1.156	0.803	1.253		0.777	0.540	34
80	1.922	1.256			1.292	0.844			43
80	1.894		1.145	0.780	1.273		0.769	0.524	34
70	1.932	1.237			1.293	0.831			43
70	1.896		1.122	0.752	1.274		0.754	0.505	34
60	1.912	1.208			1.285	0.812			43
60	1.880		1.092	0.721	1.263		0.734	0.485	34
50	1.876	1.169			1.261	0.786			43
50	1.852		1.056	0.690	1.245		0.710	0.464	34
40	1.832	1.126			1.231	0.757			43
40	1.815		1.018	0.659	1.220		0.684	0.443	34
30	1.790	1.085			1.203	0.729			43
30	1.775		0.980	0.627	1.193		0.659	0.421	34
20	1.756	1.046			1.180	0.703			43
20	1.744		0.944	0.593	1.172		0.634	0.402	34
10	1.744	1.012			1.172	0.630			43
10	1.737		0.912	0.570	1.167		0.613	0.383	34
0	1.792	1.002			1.204	0.673			43
0	1.793		0.8949	0.5492	1.205		0.6014	0.3691	34

*Corrected to reflect revised value for water at 20°C.

**Extrapolated values.

(c) The viscosity data of 90 wt% H₂O₂ have been extended to temperatures of approximately 300°F by Rocketdyne(51). These values and the appropriate values from References 43 and 34 are tabulated below and shown in Figure 3.

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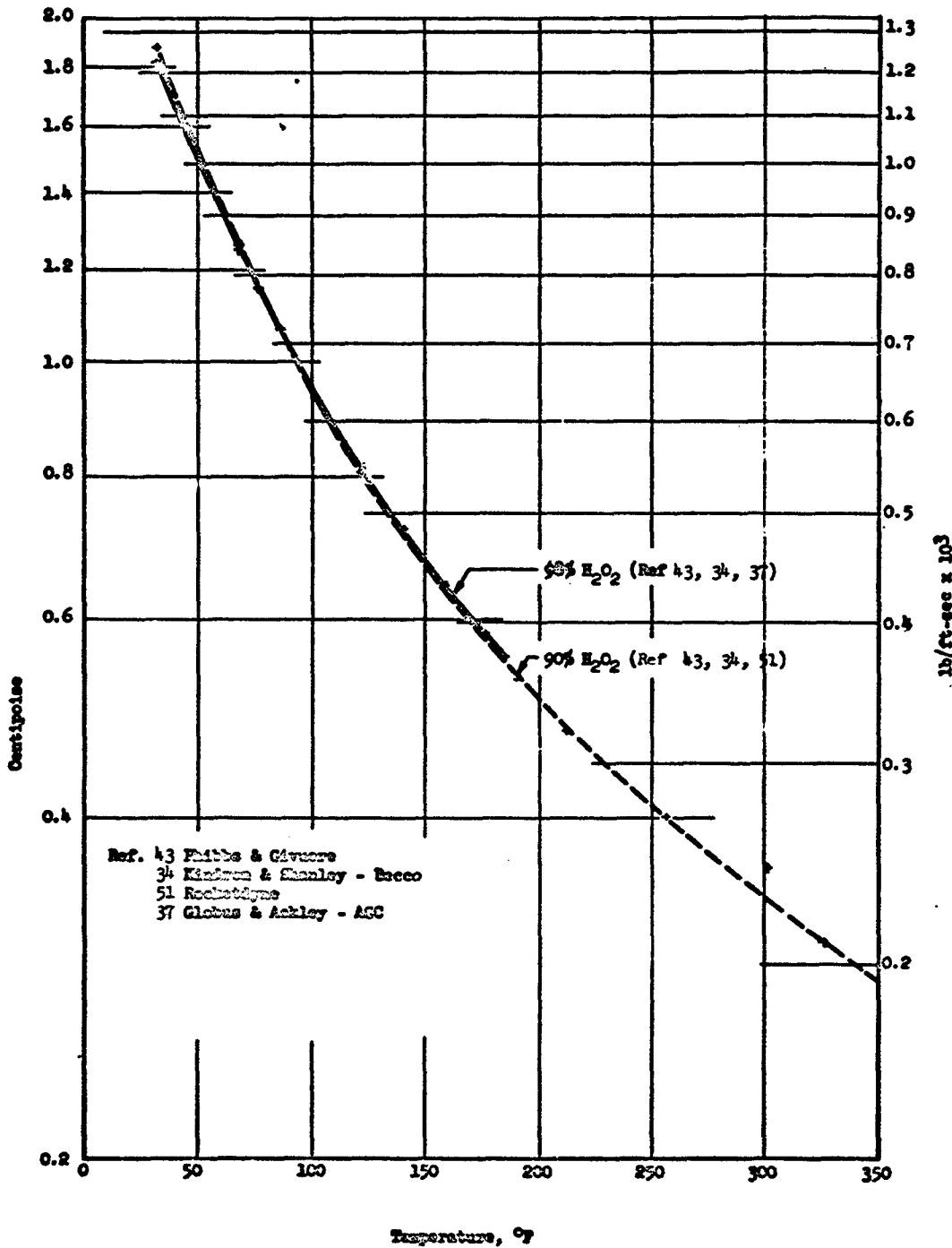


Figure 3. Viscosity of 90 and 98% H₂O₂ (u)

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(c) Viscosity of 90 Wt% Hydrogen Peroxide

Temperature		Viscosity		Ref.
°F	°C	centipoise	lb/ft-sec x 10 ³	
32	0	1.887	1.268	43
32	0	1.872	1.258	34
68	20	1.260	0.847	43
77	25	1.156	0.777	34, 51
122	50	0.803	0.540	34
122	50	0.801	0.538	51
212	100	0.479	0.322	51
257	125	0.402	0.270	51
302	150	0.362	0.243	51
326	163	0.311	0.209	51

(u) The viscosity data of 98 wt% H₂O₂ have been extended to 185°F by Aerojet-General Corporation(37). These values and those from References 43 and 34 are compiled in the following table and shown in Figure 3.

(u) Viscosity of 98 Wt% Hydrogen Peroxide

Temperature		Viscosity		Ref.
°F	°C	centipoise	lb/ft-sec x 10 ³	
32	0	1.839	1.236	43
32	0	1.812	1.218	34
68	20	1.252	0.841	43
68	20	1.250	0.840	37
77	25	1.156	0.777	34
86	30	1.068	0.718	37
104	40	0.920	0.618	37
122	50	0.816	0.548	34
122	50	0.812	0.546	37
140	60	0.724	0.487	37
158	70	0.645	0.433	37
176	80	0.583	0.392	37
185	85	0.555	0.373	37

2. Viscosity of Gaseous Hydrogen Peroxide-Water Vapor Mixtures

(u) The viscosities of hydrogen peroxide-water mixtures in the vapor state have been measured in the temperature range of 170 to 240°C, hydrogen peroxide concentration to 65 mole %, and at one atmosphere pressure by Satterfield et al.(52) On the basis of this work, they derived the equation given below for the viscosity of any H₂O₂-H₂O vapor mixture for the temperature range of 100 to 300°C and pressures near one atmosphere

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(u) $\mu = 134 + 0.35(t-100)-14y$

where μ = viscosity in micropoise, t = temperature in °C, and y = mole fraction of hydrogen peroxide in the vapor mixture. The accuracy is claimed to be $\pm 2\%$ and the presence of oxygen in concentrations below 1 mole % is stated to be insignificant.

3. Thermal Conductivity of Liquid Hydrogen Peroxide

(u) The only measured thermal conductivity data for high-strength H₂O₂ found in the literature are given below(35).

Wt % H ₂ O ₂	Thermal Conductivity			
	Btu/hr-ft-°F 32°F	Btu/hr-ft-°F 77°F	cal/sec-cm-°C x 10 ³ 32°F	cal/sec-cm-°C x 10 ³ 77°F
98.2	0.321	0.339	1.33	1.40
50.0	-	0.347	-	1.43
0.0	0.324	0.353	1.34	1.46

(u) Pratt & Whitney Aircraft(53) estimated the thermal conductivity of 98% H₂O₂ by curve-fitting the thermal conductivity-temperature relationship of water and adjusting the curve downward to coincide with the data point for 98.2% H₂O₂ at 77°F given above. Although this estimate is probably acceptable, it appears that it would be more correct to adjust the curve so that correspondence is achieved at the same reduced temperature and reduced thermal conductivity (a corresponding state type correlation). In this work such a corresponding state type adjustment has been made in the manner described below. On the basis of the thermal conductivity data for water from Reference 54 and the critical thermal conductivity of water from Reference 55, a plot of reduced thermal conductivity (k_R , k/k_c) versus reduced temperature (T_R , T/T_c) for water was prepared. Assuming H₂C₂-H₂O solutions to be water-like (i.e., obey the k_R versus T_R relationship of water), the critical thermal conductivity of 98 wt% H₂O₂ was calculated from the thermal conductivity values at 32 and 77°F given in the table above, the k_R versus T_R plot for water, and the critical temperature of 98 wt% H₂O₂ given by the equation in Section A,7. These calculations yielded critical thermal conductivity values of 0.145 and 0.143 Btu/hr-ft-°F from the 32 and 77°F thermal conductivity values, respectively. The average of the two values (0.144 Btu/hr-ft-°F) has been taken as the critical thermal conductivity of 98 wt% H₂O₂. Using this critical value and the k_R versus T_R plot, the thermal conductivity of 98 wt% H₂O₂ has been calculated at 40°F temperature intervals from 40 to 760°F. These data are given in the following table and shown in Figure 4. Note that the figure also presents the thermal conductivity of water based on the data from Reference 54 and has the data points for 98 wt% H₂O₂ and water from Reference 35 plotted on the curves.

(c) Rocketdyne(49) has calculated the thermal conductivity of 90% H₂O₂ using the empirical equation recommended by Palmer(56). These data and

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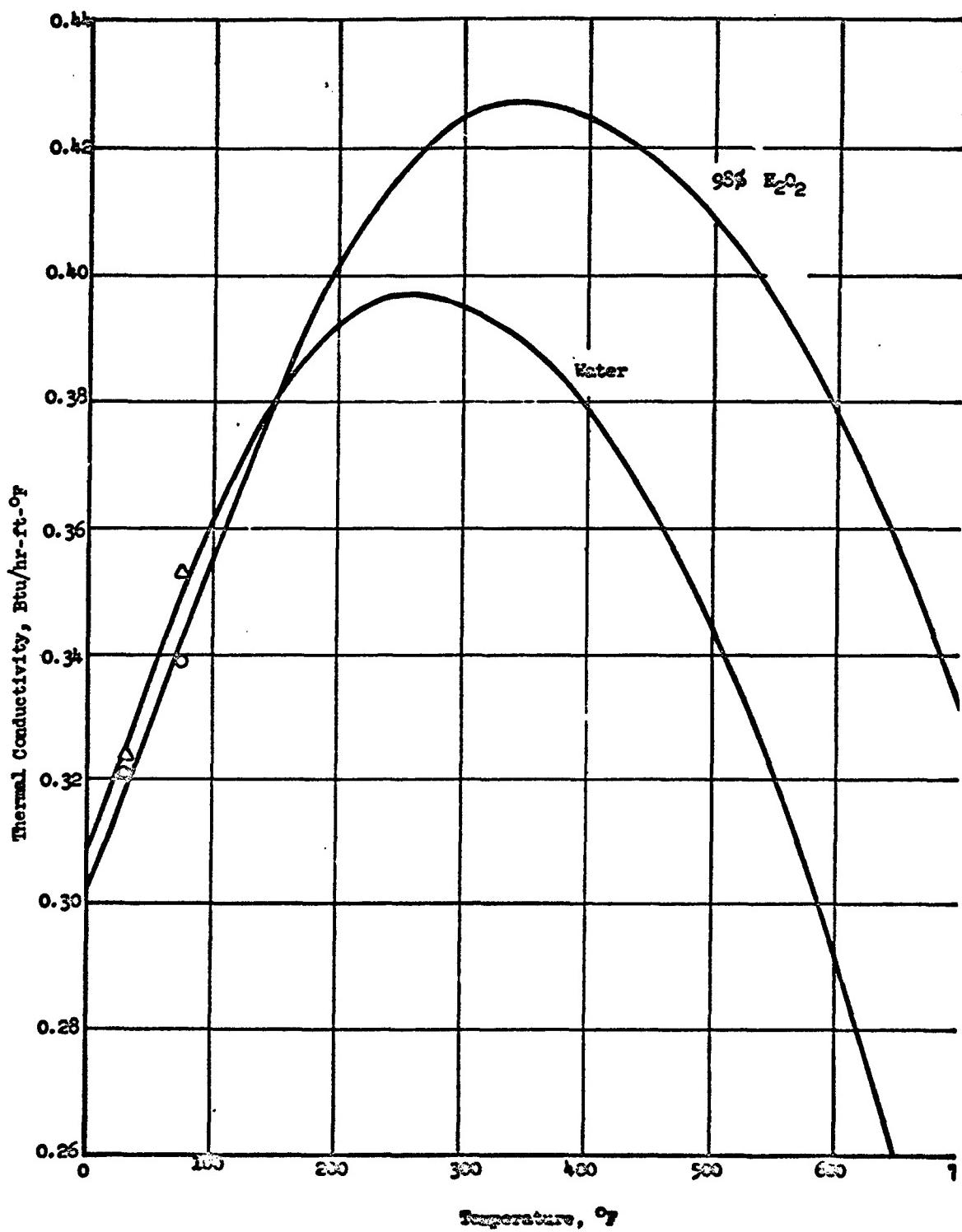


Figure 4. Thermal Conductivity of Water and 98% H_2O_2

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the approach itself have been rejected for hydrogen peroxide for two reasons: (1) the values obtained using the equation are lower than one would expect assuming the data in the table above from Reference 35 are correct, and (2) the values obtained decrease with temperature at nearly a constant rate contrary to the known behavior of water and the expected behavior of H₂O₂ (H₂O₂ is generally regarded to be a water-like substance).

(u) Estimated Thermal Conductivity of 98 Wt% H₂O₂

Temperature		Thermal Conductivity	
°F	°C	Btu/hr-ft-°F	cal/sec-cm-°C x 10 ³
32*	0	0.321	1.327
40	4.4	0.323	1.334
77*	25.0	0.339	1.401
80	26.7	0.343	1.419
120	48.9	0.364	1.506
150	71.1	0.384	1.590
200	93.3	0.401	1.657
240	115.6	0.413	1.707
280	137.8	0.421	1.741
320	160.0	0.426	1.761
360	182.2	0.427	1.764
400	204.4	0.424	1.755
440	226.7	0.420	1.736
520	271.1	0.404	1.670
560	293.3	0.392	1.622
600	315.6	0.378	1.562
640	337.8	0.361	1.493
680	360.0	0.342	1.413
720	382.2	0.319	1.320
760	404.4	0.295	1.219
849.5**	454.1	0.144	0.595

*Measured values from Reference 35 for 98.2 wt% H₂O₂.

**Calculated critical point.

4. Coefficient of Diffusion of Liquid Hydrogen Peroxide

(u) Schumb et al. (1) have reviewed the coefficient of diffusion data for liquid hydrogen peroxide diffusing into water. They find the values of Stern(57) to be the most acceptable. These values are presented in the following table.

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Hydrogen Peroxide Concentration		Temperature		Coefficient of Diffusion, D	
wt % H ₂ O ₂	normality	°F	°C	ft ² /hr x 10 ³	cm ² /sec
0.17	0.102	104.0	40	6.64	1.43
0.17	0.104	86.0	30	5.29	1.13
0.17	0.103	77.0	25	4.62	1.03
7.92	4.78	68.0	20	5.02	1.12
1.44	0.85	68.0	20	5.29	1.18
0.18	0.107	68.0	20	3.8	0.84
0.019	0.011	68.0	20	3.4	0.76
0.17	0.098	59.0	15	3.5	0.73
0.17	0.102	50.0	10	2.1	0.46
0.17	0.101	41.0	5	1.7	0.39
0.17	0.102	32.0	0	2.4	0.53

Measurements of the coefficients of diffusion of hydrogen peroxide into methyl alcohol, ethyl alcohol, acetone, and ether have also been measured by Stern(57). These coefficients were found to differ significantly from those found for diffusion into water.

5. Coefficient of Diffusion of Hydrogen Peroxide Vapor

The coefficient of diffusion of hydrogen peroxide vapor into air at 140°F (60°C) and one atmosphere pressure has been measured by McMurtrie and Keyes(58). The value is

$$D = 0.188 \pm 0.004 \text{ cm}^2/\text{sec} = 0.723 \pm 0.015 \text{ ft}^2/\text{hr}$$

E. ELECTROMAGNETIC PROPERTIES

1. Electrical Conductivity of High-Strength Hydrogen Peroxide Solutions at 77°F (25°C) for 50% (v/v) H₂O₂

The recommended values are taken from Schurz et al.(1) which were derived by smoothing the data of Gignac and Corfman(60). The values for 90 to 100 wt% H₂O₂-H₂O solutions are given in the table below. Values for lower concentrations (0 to 90 wt% H₂O₂) can be found in Reference 1.

wt% H ₂ O ₂	1.3	Permittivity Value, D (77°F)				
		0.0	0.2	0.4	0.6	0.8
90		980	981	983	985	986
91		983	989	992	993	995
92		987	989	990	992	994
93	1.4	0.06	0.07	0.09	0.11	0.13
94		0.14	0.16	0.18	0.20	0.21

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<u>% wt H₂O₂</u>	Refractive Index, D (77°F)				
	<u>0.0</u>	<u>0.2</u>	<u>0.4</u>	<u>0.6</u>	<u>0.8</u>
95	023	025	027	028	030
96	032	034	035	037	039
97	041	042	044	046	048
98	049	051	053	055	056
99	058	060	062	063	065
100	067				

2. Constants Derived from Refraction Data for Anhydrous Hydrogen Peroxide (59) and (60)

Specific refraction, r_D , cm^3/g , 77°F (25°C)	0.1705
Molar refraction, $[R]_D$, cm^3/mole , 77°F (25°C)	5.801
Polarizability, $\alpha \times 10^{24}$, $\text{cm}^3/\text{molecule}$, 77°F (25°C)	2.30
Molar dispersion, $[R]_G - [R]_C$, cm^3/mole , 63°F (20°C)	1.3576
Dispersion constant, $\alpha \times 10^{-30}$, sec^{-2} , 63°F (20°C)	8.479
Characteristic frequency, $v_o \times 10^{-15}$, sec^{-1} , 63°F (20°C)	2.979
Molecular radius, Å	1.32

3. Dipole Moment

A number of values for the dipole moment of hydrogen peroxide have been given in the literature. These various values have been discussed by Schumb et al. (1) but no single value has been recommended. The available values are given below along with their methods of derivation.

H ₂ O ₂ in dioxane	2.13×10^{-13} esu cm (Ref. 61)
H ₂ O ₂ in ethyl ether	2.06×10^{-13} esu cm (Ref. 61)
H ₂ O ₂	2.26×10^{-13} esu cm (Ref. 62)
H ₂ O ₂	2.1×10^{-13} esu cm (Ref. 63)

The first two values were experimentally determined by the dilution method, the third value was deduced from observations of the Stark effect in the microwave spectrum of hydrogen peroxide, and the last value was calculated from structural considerations.

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4. Dielectric Constant

(u) The recommended values for the dielectric constant of hydrogen peroxide-water solutions are those of Gross and Taylor⁽³⁾. On the basis of their values, the dielectric constants of 90, 93, and 100 wt% H₂O₂ have been graphically defined and are presented in the table below.

Temperature °F	°C	Dielectric Constant		
		90 wt% H ₂ O ₂	59 wt% H ₂ O ₂	100 wt% H ₂ O ₂
-22	-30	110.7	106.8	105.7
-4	-20	102.6	99.0	93.1
14	-10	95.1	91.7	90.8
32	0	89.6	85.3	84.4
50	10	82.6	79.4	78.5
68	20	77.1	74.0	73.2
86	30	72.2	69.4	68.5

5. Electrical Conductivity

(c) The known values of specific conductivity at 77°F are given below for various H₂O₂-H₂O solutions.

Wt% H ₂ O ₂	Specific Conductivity, $\text{ohm}^{-1} \text{cm}^{-1} \times 10^6$		Ref.	Wt% H ₂ O ₂	Specific Conductivity, $\text{ohm}^{-1} \text{cm}^{-1} \times 10^6$		Ref.
	99.9	99.2		99.0 (super pure)	93.7	93.5	
99.9	0.39	0.4	65	65.8	5.1	5.3	65
99.2			64	53.5			65
99.0 (super pure)	0.49*		67	40.5	5.5		65
93.7	0.72	0.72	65	25.4	4.0		65
93.5	0.82		65	11.8	2.3		65
90.0 (super pure)	2.2*		67	0	0.5		65
79.7	3.3		65				

~~Gross & Taylor~~ regards these data points as being extremely reliable. Testing was performed on "super pure" H₂O₂. The "super pure" 90.0% H₂O₂ was made by diluting 100% H₂O₂ with distilled water.

6. Magnetooptic Rotation (Optical Constant)

(u) Hydrogen peroxide and its solutions in water are not optically active but, when placed in a magnetic field, will rotate the plane of polarized light. This is the Faraday effect or phenomenon of magneto-optic rotation. This effect is given quantitatively by the expression

$$\theta = VIM$$

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where α is the angle of rotation, V is the Verdet constant, l is path length, and H is the field strength.

The Verdet constants of hydrogen peroxide-water solutions at 50°F have been measured by Giguere and Feozy(1) using light of wave lengths 5893, 5780, 5461, and 4358 Å. Their values are given in the table below.

wt% H ₂ O ₂	Verdet Constant, rad/cm ² sec x 10 ³			
	5893 Å	5780 Å	5461 Å	4358 Å
100.0*	11.43	11.90	13.52	22.65
95.0	11.60	12.03	13.04	22.70
78.5	11.93	12.45	14.07	23.45
62.0	12.30	12.80	14.43	24.11
50.9	12.53	12.93	14.60	24.22
38.1	12.69	13.15	14.85	24.47
18.1	12.91	13.33	15.13	25.00
0.0	13.09	13.64	15.40	25.21

*Extrapolated

7. Magnetic Susceptibility

Hydrogen peroxide, like water, is diamagnetic. After studying the various data available, Schubert et al.(1) recommend the following values for anhydrous hydrogen peroxide at approximately 50°F.

Volume susceptibility, k , cgs em ³ /cm ³	-0.73×10^{-6}
Mass susceptibility, χ_g , cgs em ³ /g	-0.50×10^{-6}
Molar susceptibility, χ_m , cgs em ³ /mole	-17×10^{-6}
Permeability, P , cgs cm ³ /sec	0.999998

There is no indication that temperature affects the mass susceptibility of liquid hydrogen peroxide, even when extrapolated. However, on freezing the susceptibility becomes more positive by about 2.4%. No measurements of the magnetic susceptibility of hydrogen peroxide vapor have been made, but it is presumed that there is no change in mass susceptibility upon vaporization.

The recommended values for the mass susceptibility of hydrogen peroxide-water solutions can be obtained from the following equation:

$$\chi_g \times 10^6, \text{ cgs em}^3/\text{g} = -0.730 + 0.218 w$$

where w is the weight fraction H₂O₂ in the solution.

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APPENDIX II

DECOMPOSITION AND STABILIZATION OF HYDROGEN PEROXIDE (u)

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APPENDIX II

DECOMPOSITION AND STABILIZATION OF HYDROGEN PEROXIDE

A. DECOMPOSITION PROCESSES

The decomposition of hydrogen peroxide may proceed in either the liquid or the vapor phases. In the vapor phase, a thermal or homogeneous decomposition occurs at elevated temperatures, whereas at lower temperatures, a catalytic or heterogeneous decomposition occurs. Liquid-phase decomposition proceeds through catalytic effects (heterogeneous) as well as through radiation, electrolysis, and thermal effects (homogeneous decomposition). Schub, Satterfield, and Wentworth, in their book *Hydrogen Peroxide* (1) discuss the modes of decomposition and provide referenced experimental evidence. This book should be utilized as a primary reference source.

1. Vapor Phase Decomposition

a. Homogeneous Decomposition

At temperatures above 425°C (800°F) a homogeneous decomposition occurs. Hoare, et al., (2) have shown that at these elevated temperatures the decomposition is a second-order homogeneous reaction. They indicate that their results are in agreement with the results of other workers. Satterfield (3) and Monger (4) have also shown that at sufficiently high concentrations, a completely homogeneous reaction can be propagated at much lower initial vapor temperatures. For example, Monger (4) achieved a propagating vapor phase reaction by spark ignition at an initial temperature of 159°F at a total pressure of 13 mm Hg and 72.2 mole percent H₂O₂ in the vapor (see also Section B, of Appendix V).

Kinetics studies at Laval University (5) indicate an activation energy of 42.5 kcal/mole for high-temperature hydrogen peroxide dissociation. This value is in good agreement with the dissociation energy of the O-O bond.

On the basis of this study the authors of Reference (5) postulate the following mechanism for the thermal decomposition of hydrogen peroxide. The initial and rate-determining step of the reaction is the splitting of the O-O bond:



The hydrogen peroxide molecule is then attacked by the OH radicals, thereby producing HO₂ radicals. These in turn react to form water and oxygen:

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Hoare⁽²⁾ calculated the rate constant for the initial splitting of the O-O bond to be $10^{15.4} \exp(-42000/RT) \text{ 1.0/mole-sec.}$

b. Heterogeneous Decomposition

(c) At temperatures less than 425°C, vapor-phase decomposition occurs heterogeneously in a first-order reaction. Schumb, Satterfield, and Wentworth⁽¹⁾ report that the rate of heterogeneous vapor-phase decomposition is characterized by an extraordinary sensitivity to slight changes in the physical nature of the reaction-vessel surface, as well as in its chemical composition. The catalytic activity of surfaces in contact with H_2O_2 vapor appears to be similar to that of submerged surfaces⁽⁶⁾. The least active catalytic materials include fused pyrex, tin, and aluminum. Pyrex when treated with hydrofluoric acid or chromic acid exhibits increased reactivity⁽¹⁾. Upon fusing of the pyrex surface a decrease in activity will be noted.

(u) The most active catalytic surfaces include platinum and silver. Becco has reported⁽⁷⁾ that silver-gold alloys (containing 5 to 40% gold) exhibit an increased reactivity over that shown by pure silver pellets. They attribute this increase of reactivity to the larger surface area of pellets which are formed from metal-metal mixtures. Satterfield⁽⁸⁾ has noted that platinum does not decrease in reactivity after prolonged contact with H_2O_2 vapor at elevated temperatures. This is in direct contrast to 304 stainless steel which will decrease in reactivity under similar conditions. Satterfield has noted⁽⁹⁾ that under most conditions, mass transfer and surface reaction are both significant. He unexpectedly found that true surface activity goes through a maximum with increased temperature.

(c) The thermal decomposition of hydrogen peroxide has been successfully utilized in gas generators^(10,11,12) where the distinction between vapor-phase and liquid-phase decomposition is not clear. Reitlinger⁽¹¹⁾ reported a 20-min successful firing. The reactor was heated to a pre-determined temperature and 90% unstabilized H_2O_2 was introduced. The reaction immediately ensued with a corresponding rise in temperature. As the gases were carried away, the incoming peroxide served to cool the reactor, thereby decreasing the rate of reaction. No pressure surges or pressure oscillations were observed.

(c) Rocketdyne⁽¹²⁾ was successful in demonstrating a gas generator which embodied the non-catalytic decomposition of 90% hydrogen peroxide. The gas generator was packed with nichrome and stainless-steel wire screens which behave as "thermal" catalysts at elevated temperatures. Operation was continued for 75 sec with injection densities (throughput) up to 4 lb/in.²/min. The ignition at the reactor walls was found to be unsatisfactory; however, Rocketdyne reported that programmed starts incorporating

preheating of the packing by a pilot flow of propellant (decomposed catalytically) were extremely smooth and repeatable. (c)

(u) The vapor-phase decomposition at pressures less than 1 mm and at both ambient and elevated temperatures has been studied (15). It was found that oxygen at these low pressures had no appreciable effect on decomposition rate, whereas water vapor slightly retarded the reaction. Higher pressures of oxygen or nitrogen retarded decomposition appreciably. The velocity of decomposition, calculated for 1 mm pressure of peroxide at 50°C by the theory of absolute reaction rates, was 0.70×10^{13} mol/cm.²sec, in agreement with the measured value of 0.76×10^{13} mol/cm.²sec.

(u) At temperatures below 300°F, the vapor-phase decomposition rate was found to increase with a decrease in temperature (14). The effect is attributed to the increase in the amount of adsorbed PbO_2 at the surface as the temperature is lowered. Thus a smooth transition might be expected from vapor-phase decomposition rates to liquid-phase decomposition rates. Such a smooth transition has been observed.

2. Liquid-Phase Decomposition

a. Heterogeneous Decomposition

(u) The heterogeneous decomposition of liquid hydrogen peroxide occurs via surface or solution catalysis. Surface catalysts, however, exhibit markedly varying degrees of activity even though they may be of similar composition. For example, the catalytic activity of graphite is quite different from that of sugar charcoal and, likewise, crude boneblack is still different from the others.(1)

(u) Metallic lead is one of the more active heterogeneous catalysts(1). A white oxide is formed, $\text{Pb}(\text{OH})_2$, which is further oxidized to red lead oxide PbO_2 . Subsequent to the formation of the red lead oxide a violent catalysis occurs. Mercury has also been shown to be clearly catalytic⁽¹⁾. The mercury apparently undergoes valence changes necessary for catalysis.

(u) Copper, silver, and gold all exhibit surface catalysis⁽¹⁾. Of these three metals, silver is by far the most active catalyst. Baumgartner, et al., (15,16) have studied the heterogeneous decomposition of 50% hydrogen peroxide on silver as a function of bulk solution temperature, silver surface temperature, and pressure. Two distinct decomposition regions exist with an abrupt transition from one region to the other. The data at the low temperatures indicate that chemical reaction at the silver surface controls the rate of peroxide decomposition, and this rate of decomposition strongly influences the transition between both regions. At high temperatures, the decomposition is rate-limited by heat transfer. At constant bulk solution temperature, the silver surface temperature and the H_2O_2 decomposition rate increase with increasing pressure in a manner expected for a heat-transfer-limited process.

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At constant pressure with increasing bulk solution temperature, the silver surface temperature slowly increases while the hydrogen peroxide decomposition rate and the silver loss rate slowly decreases. Satterfield(17) also reported that the rate of decomposition was dependent upon the catalyst surface temperature, reaching a maximum at the onset of film-type heat transfer. He observed that the maximum rates for 90% H_2O_2 were evident at about 150°F.

(u) Because of non-reproducibility in the reactivity of silver catalysts towards hydrogen peroxide, RIC developed a method of altering the surface (18) by treatment with samarium nitrate ($Sm(NO_3)_3$). This treatment substantially improved the reproducibility of the catalyst's activity. Another method of enhancing the catalytic activity of silver is by alloying it with gold or platinum which reduces vapor binding at the catalyst surface (19). These alloys have been found to be superior in activity to a $Sm(NO_3)_3$ -treated silver catalyst.

(c) Rocketdyne⁽²⁾ has reported the development of a high-temperature refractory-type catalyst for H_2O_2 . The basic coating, which is applied to stainless-steel screens, is composed of silver, manganese dioxide, and aluminum oxide. Other additives were considered with respect to catalytic activity. Glass was introduced to promote better adherence to the surface and gold was added to increase the activity of the basic catalyst. Samarium oxide, Sm_2O_3 , was used to eliminate the need for final activation. Rocketdyne demonstrated the ability of the catalyst to sustain efficient decomposition of high-strength peroxide over a total duration of 360 sec.

(u) The elements palladium and platinum are active catalysts⁽¹⁾. In the hydrogenated state, palladium becomes even more active. The presence of alkali increases the reactivity of platinum while acid inhibits it.

(u) Another well-known and active catalyst is manganese. In the case of the manganese ion, it is thought that no catalysis occurs until the solubility product for manganese hydroxide is reached. Thus the degree of alkalinity determines the reactivity of the manganese ion. The California Institute of Technology has examined various catalysts for their hydrogen peroxide gas generator studies.⁽²⁰⁾ They concluded that the oxides of lead, cerium, silver, manganese, and vanadium yield good, solid catalysts.

(u) Decomposition of hydrogen peroxide in the liquid phase also occurs by solution or homogeneous catalysis. These are substances which exert a catalytic effect while in true molecular solution. Examples of these substances⁽¹⁾ are the halogens (except fluorine), iron, copper, permanganate, chromium, molybdenum, and tungsten. Liquid catalysts, however, tend to deposit a residue on exposed surfaces, but they show negligible ignition delays⁽²¹⁾ --an excellent feature in gas generation.

b. Homogeneous Decomposition

(u) The homogeneous decomposition of hydrogen peroxide in the liquid phase may be initiated thermally, by radiation, or by electrolysis.

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Undoubtedly, the least significant of the decomposition processes is brought about by pure thermal effects.

(u) Decomposition of hydrogen peroxide may occur through photochemical or radiochemical processes but it is dependent upon wavelength. Peroxide is not affected by exposure to light of a wavelength greater than about 3300 Å.⁽¹⁾ Hydrogen peroxide absorbs in the infrared region; however, these frequencies do not cause decomposition. Bainton and Radettini⁽⁴¹⁾ have indicated that for intensities up to about 10⁻⁷ quanta/1.0 sec and concentrations up to 20 molar, the rate is directly proportional to the hydrogen peroxide concentration and to the square root of the intensity. Similarly, radiochemical decomposition of concentrated hydrogen peroxide⁽¹⁾ (via X-ray or γ -radiation) is characterized with reaction rates proportional to concentration of the peroxide and to the square root of the intensity.

(u) Hydrogen peroxide may be electrolytically decomposed to form hydrogen and oxygen. At high current densities the overall process is:



Interestingly, as the current density is decreased, the yield of hydrogen becomes less and less and finally disappears. However, the oxygen is liberated at the anode quantitatively in the proportion of one mole of oxygen for every two Faradays of electricity.⁽¹⁾ The reason for the changing proportion of H_2 at the cathode is not thoroughly understood. A reasonable explanation would be that the hydrogen reacts with the peroxide at decreasing current densities, thereby producing two moles of water.

B. STABILIZATION

(u) Hydrogen peroxide when free from contaminants and when stored in a thoroughly clean container of non-catalytic material is a very stable substance exhibiting minimal decomposition during storage. To ensure proper stability, the factors which affect the stability of peroxide must be understood and appropriate action taken accordingly. These factors may be conveniently categorized as being external or internal. External factors include surface effects such as materials of construction and the surface-to-volume ratio. Other external factors deal with the effects of temperature and radiation. The chemical methods of stabilizing hydrogen peroxide may be considered internal factors. These methods include adjustment of pH and the addition of various stabilizing agents. These stabilizers serve to restrain peroxide decomposition resulting from catalytically active contaminants.

1. External Factors

a. Surface Effects

(c) The decomposition of hydrogen peroxide during storage is generally a result of heterogeneous reaction at the container walls. According

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to Schumb, Satterfield, and Wentworth, (1) laboratory experiments have shown that the decomposition rate of H_2O_2 is roughly proportional to the surface-to-volume ratio. This is in agreement with Price (2) who found that decomposition of peroxide is heterogeneous and dependent upon the unit area of the immersed surface. Thus, it can be readily seen that decomposition may be minimized by reducing the surface-to-volume ratio to as small a value as possible.

(u) An equally important surface effect is the catalytic activity of the storage vessel material. Laboratory containers constructed of borosilicate glass (Pyrex) are quite suitable for concentrated H_2O_2 handling and storage. (1) Materials of construction of particular interest for hydrogen peroxide are aluminum, tin, and certain stainless steels. Shell Development Company (24) is of the opinion that containers of very pure tin would cause less heterogeneous decomposition than containers made of very pure aluminum. The tin would stabilize some of the catalytic ions in solution in the hydrogen peroxide. Whatever material is used, its surfaces must be smooth and free of all possible copper, chromium, iron, lead, or other catalytic elements to achieve the stabilities required for long-term storage. Schumb, Satterfield, and Wentworth (1) have shown that the decomposition of 70% hydrogen peroxide is more than doubled when a 99.0% aluminum storage container is substituted for a very pure aluminum container. They state that one-half of 1% or less of impurities in a metal can cause a distinct rise in the decomposition rate of hydrogen peroxide. Thus it is necessary to properly passivate any surface that may come in contact with H_2O_2 to minimize the rate of decomposition. Again it is important to note that best results are obtained when the container surface is as smooth as possible to minimize surface area and to decrease the chance for inclusions of catalytic material. See also Appendix III on materials compatibility and Section E of Appendix IV for the recommended cleaning and passivation procedures.

b. Temperature Effects

(u) One of the more important factors in controlling the decomposition of hydrogen peroxide is the control of the bulk solution temperature. Schumb, Satterfield, and Wentworth (1-2) have noted that in the 50 to 70°C temperature range, a 10°C rise in temperature increases the decomposition rate by a factor of 2.2 ± 0.1 . In Finsch's studies on solid low-temperature storage of 90 and 93% H_2O_2 in passivated Pyrex glass containers, Du Pont concludes that in the solid state at -60°C no decomposition of either 90 or 93% peroxide could be detected. At -50°C the 50% H_2O_2 (solid) still showed no decomposition; however, the 93% H_2O_2 , which was in liquid-solid equilibrium, showed a barely detectable amount of decomposition. At 0°C the peroxide is liquid and the decomposition rates vary considerably, depending on the source of H_2O_2 . Decomposition ranged from undetectable to a maximum of 0.23 per year. Rocketdyne (26,27) has similarly studied the rate of decomposition of 90 and 93% hydrogen peroxide; however, these studies were conducted at elevated temperatures. A Pyrex glass apparatus was utilized which had surface-to-volume

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and vapor volume-to-liquid volume ratios of 6.0 each. Pressures of up to 160 psia were used with the 90% peroxide and of up to 200 psia with the 90% H_2O_2 . The results of this study are given in Table I and indicate that the decomposition rate of H_2O_2 increases greatly at elevated temperatures. Thus, it can readily be seen that the stability of hydrogen peroxide during storage is directly affected by temperature and that the storage temperature should be kept as low as practical to minimize decomposition.

c. Radiation Effects

(u) The photochemical and radicical decomposition of hydrogen peroxide can have a significant effect on storage stability.(1). Artificial light sources do not cause any appreciable difficulties because the wave lengths involved are, for the most part, not absorbed by the peroxide. The ultraviolet wavelengths from sunlight could cause appreciable decomposition; however, glass quite effectively filters out the short wavelength radiation of sunlight. Thus, to ensure storage stability, radiation must be minimized by keeping peroxide storage containers out of direct sunlight and away from high-intensity radiation (x-rays and γ -rays).

2. Internal Factors

a. Acidity (pH)

(u) Hydrogen peroxide may be stabilized by adjusting the pH of the solution. Schumb, Satterfield, and Wentworth(1) state that uncontaminated solutions of hydrogen peroxide are most stable at a pH slightly more acid than the "natural" pH. It has been observed that maximum stability occurs in the pH range of 4.0 + 0.5. Also, the more concentrated solutions appear to be more stable than the more dilute solutions, and variation in pH over the range of 2.5 to 5.5 has only a slight effect on rate of decomposition. The decomposition rate for concentrated H_2O_2 is seen to significantly increase as the solution becomes more alkaline. It may be concluded that catalytic decomposition may occur even in the most carefully purified hydrogen peroxide by mechanisms which are favored by conditions more or less acid than about 4 to 5 pH. Therefore, careful control of pH is necessary for storage stability.

(u) In the presence of various metal ions, e.g., Fe^{+3} , Cu^{+2} , or Cr^{+3} , a sharp maximum rate of decomposition will occur in the vicinity of pH 3.5. This peak does not exist with pure hydrogen peroxide. It is thought(1) that the sharp increase in decomposition rate with pH is associated with the progressive hydrolysis of the dissolved catalyst to form a colloidal hydrous oxide (or possibly slightly soluble basic salts) having a relatively large, catalytically active surface in contact with the H_2O_2 solution. The rapid decline in the rate of decomposition upon further increase in pH may be attributed to the coagulation of the colloid and thus to a reduction in surface area exposed. As the solution becomes more alkaline, it will be noted that decomposition increases as with pure H_2O_2 . Interestingly, neither silver nor manganese ions exert any pronounced catalytic activity at sufficiently acid

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TABLE I
RATE OF DECOMPOSITION OF HYDROGEN PEROXIDE

Temp., °C.	90% H ₂ O ₂			98% H ₂ O ₂		
	Total Wt. Loss, g./hr.	H ₂ O ₂ Wt. Loss, g./hr.	Half Life, hr.	Specific Rate Constant, hr. ⁻¹	Total Wt. Loss, g./hr.	H ₂ O ₂ Wt. Loss, g./hr.
123.0.2	0.0034	0.0023	6930.0	10.0x10 ⁻⁵	----	----
140.0.4	—	—	—	—	0.0148	0.0152
212.0.4	0.092	0.10	679.0	10.2x10 ⁻⁴	0.170	0.175
257.0.5	0.62	0.69	83.0	7.9x10 ⁻³	2.73	2.81
275.0.8	3.80	4.30	15.4	4.5x10 ⁻²	----	----
301.0.4	—	—	—	—	16.7	17.1
317.0.8	27.0	30.0	2.2	3.1x10 ⁻¹	154.0	153.0
					0.40	0.40
					1.75	1.75

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conditions. The ions are presumably present in solution as the simple cations. When, however, the pH is increased sufficiently so that the oxides of these metals may precipitate, a rapid and great increase in the decomposition rate of the peroxide ensues. Thus it can be concluded that the pH value at which a peroxide solution is most stable may vary depending upon the catalytic ions and stabilizers present.

b. Stabilizing Agents

(u) If hydrogen peroxide could be prepared and kept in the total absence of catalytically active materials, no stabilizers would be needed to ensure storage for long periods at ordinary temperature without appreciable loss by decomposition. Stabilization, aside from control of the pH and temperature of the peroxide solution, consists of inactivating catalytically active substances which may be present, either dissolved or suspended in the solution, or held in the walls of the container. It does not consist of thwarting the autoclave decomposition process of hydrogen peroxide itself.⁽¹⁾ Thus, the addition of stabilizing agents to concentrated hydrogen peroxide solutions of exceptional high purity in a clean and inert container fails to reduce further the rate of decomposition of the peroxide solution to any important degree. If the specific nature of the impurity were known, it might be possible to choose a stabilizer on the basis of its specific action on the impurity. Most often, however, the nature of the contamination is unknown and a non-specific stabilizer may be more desirable. Further limitations on acceptable stabilizers are set by the deteriorating action of the hydrogen peroxide on the stabilizer and by the various ways in which the hydrogen peroxide may be used.

(u) A large number of stabilizers, both inorganic and organic, have been tested with hydrogen peroxide solutions. Among these substances, the most notable success appears to have been obtained with sodium stannate or with 8-hydroxyquinoline (oxine), each in the presence of a soluble pyrophosphate, or a phosphate-pyrophosphate mixture. These three substances (stannate, oxine, and phosphate) are discussed in the following paragraphs.

(1) Stannate

(c) Sodium stannate ($\text{Na}_2\text{SnO}_3 \cdot 3\text{H}_2\text{O}$) forms colloidal hydrous stannic oxide ($\text{SnO}_2 \cdot 3\text{H}_2\text{O}$) by its hydrolysis. This material absorbs catalytic ions, such as ferric ions, in an effective manner and hence improves the stability of contaminated hydrogen peroxide. Shell Development Company⁽²³⁾ has shown that 90% E_2O_3 stabilized with sodium stannate can be stored in a Pyrex container with a decomposition rate of 0.0003 year^{-1} . The addition of the stannate affects the activity of the surface in contact with it, reducing this activity generally to a consistent value for a particular surface preparation.⁽²⁴⁾

(u) If sodium stannate is added in excessive proportions, the pH of the system increases due to the hydrolysis of the sodium stannate

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and this may result in a reduction of peroxide stability. Stannate is most effective if the pH of the hydrogen peroxide solution falls between 3.5 and 6. At a pH of 2 or of 7, the decomposition rate for the same solution may rise as much as twentyfold. Sodium stannate is particularly effective in the stabilization of hydrogen peroxide against ferric ion. An optimum amount of SnO_2 (added as $\text{Na}_2\text{SnO}_3 \cdot 3\text{H}_2\text{O}$) may range from 1 to 60 ppm, and the ratio of stannate to ferric ion may vary from 13 to 26 for iron contents above 0.3 ppm. However, sodium stannate is not outstanding in its effectiveness against contamination by copper compounds. To restrain adequately the catalytic influence of as little cupric ion as 0.1 ppm it may be necessary to add up to 65 ppm of SnO_2 (added as stannate).

(c) Shell Development Co.⁽⁶⁾ has reported success in developing an effective stannate stabilizer solution. This solution has been obtained by partially neutralizing sodium stannate or potassium stannate in 90% H_2O_2 . Addition of this solution to 90% H_2O_2 of initial high stability and further neutralization in situ have given remarkably stable hydrogen peroxide (decomposition rates of 0.04 to 0.08%/day at 100°C). If the 90% hydrogen peroxide is of lower initial stability, it can be inhibited only to 0.2%/day decomposition at 100°C by this means. By passage through a bed of stannic hydrate solids precipitated from sodium stannate solution, 90% H_2O_2 of lower initial stability can be improved to give a decomposition rate of about 0.16%/day at 100°C.

(2) Oxine⁽¹⁾

(u) Of the numerous stabilizers which have been studied for use in concentrated hydrogen peroxide, particular mention has been made of such organic substances as 8-hydroxyquinoline (oxine). This stabilizer is often used as the pyrophosphate derivative or in conjunction with a soluble phosphate or pyrophosphate. The mechanism of the stabilization process involving oxine is not entirely clear in all its details. In the presence of iron contamination, oxine alone has little if any protective action, yet in the presence of phosphate, or preferably pyrophosphate, it makes an effective stabilizer against the influence of small concentrations of certain catalytic contaminants, including iron compounds. The Germans during World War II stabilized their H_2O_2 for various military purposes with oxine; however, like other organic compounds, gradual oxidation by hydrogen peroxide occurs on long-term storage. This becomes more probable if contamination by ferric iron has taken place in the hydrogen peroxide solution because the oxidation of oxine by hydrogen peroxide is markedly catalyzed by ferric compounds. However, if the stabilizer also contains pyrophosphate ion, the ferric ion may become inactivated by interaction with pyrophosphate ion, so that the oxidation of oxine is reduced to the extent that the stabilizing effect of the mixture may be prolonged for many months of storage, even if slight contamination by ferric ion occurs.

(3) Phosphates⁽¹⁾

(u) Sodium pyrophosphate ($\text{Na}_2\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$) alone is capable of holding in check at least 10 ppm Fe^{+3} contamination, but it cannot effectively control even a few ppm of copper compounds. Its protective mechanism appears to consist of reaction with such dissolved catalytic ions as Fe^{+3} which are

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either precipitated or, in the presence of an excess of pyrophosphate, converted into relatively stable complexes. In either case, the catalytic effect is largely eliminated. It seems improbable that pyrophosphate should directly influence the heterogeneous decomposition process, except insofar as it may inactivate metal ions which otherwise may lead to the formation of catalytically active solid products. It is also to be born in mind that pyrophosphate ion is itself subject to gradual hydrolysis at ordinary temperatures in aqueous solutions:



It is, of course, essential that the pyrophosphate employed for stabilization purposes should itself be chemically pure and, in particular, free from iron contamination.

The optimum proportion of pyrophosphate for stabilization against ferric ion has been studied by Schmid⁽²⁹⁾. He found that maximum stabilizations for iron-contaminated concentrated hydrogen peroxide solutions occurs at a ratio of $\text{P}_2\text{O}_7^{-4}$ to Fe^{+3} of 3.8 to 9.0. The pH of these solutions should remain distinctly acid.

Sodium hypophosphite, NaH_2PO_2 , has been found to be slightly less effective against ferric ion than pyrophosphate, but equally effective against cupric ion. Ferric pyrophosphate is distinctly catalytic in action.

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APPEND. III

COMPATIBILITY OF MATERIALS WITH
HYDROGEN OXIDE

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APPENDIX III

COMPATIBILITY OF MATERIALS WITH
HYDROGEN PEROXIDE

A. MATERIALS EVALUATION TESTS

The evaluation of the compatibility of materials with hydrogen peroxide requires definition of both the effect of the material on the hydrogen peroxide and the effect of the hydrogen peroxide on the material. Test procedures are often specifically designed to define: (1) the quantitative effect of the material on the rate of decomposition and the stability of the H₂O₂, (2) the qualitative effect of the H₂O₂ on the material itself such as corrosion of metals by either the liquid or vapor, and the hardening, swelling, blistering, deterioration, dissolving, etc. of plastics and elastomers, (3) the possible formation of impact-sensitive mixtures of the materials or of components of the material with H₂O₂ during contact, and (4) in special instances, the suitability of the material for the intended application.

1. Compatibility Tests

The effect of materials on H₂O₂ decomposition and the effect of the H₂O₂ on the materials is normally evaluated by immersion of the sample in the H₂O₂ with a standard wetted surface-to-H₂O₂ volume ratio, at controlled standard temperatures, and for standard periods of time. FMC Corporation appears to have conducted the most comprehensive standardized compatibility tests and has adopted the following standard test conditions: surface-to-H₂O₂ volume ratio of 0.33 in.²/in.³, temperatures of 30 and 66°C, and time periods of 4 weeks and 1 week for the respective standard temperatures. Their complete test procedure is given in Reference 1. The test is generally applied to solid materials but can, with slight variation, be applied to greases.

Prior to performing compatibility tests, all the surfaces of the samples and the glassware must be scrupulously cleaned and passivated. The procedures for cleaning and passivation utilized by FMC have been developed by experience or by laboratory studies and are presented as part of the compatibility test procedure given in Reference 1. A more thorough discussion of preparation of materials for H₂O₂ service is presented in Appendix IV. The results of the immersion compatibility tests for the effect of the material on the rate of decomposition of the H₂O₂ are reported as the percent of active oxygen loss (% AOL) from the contacted H₂O₂ per week at 66°C (151°F) and per month at 30°C (86°F).

The effect of the H₂O₂ on the material itself is determined visually, e.g., corrosion, staining, bronzing, pitting, swelling, bleaching, blistering, surface disintegration, etc. Weight or dimension change measurements are not normally included.

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2. Thermal Stability Tests

Following a compatibility test of a material, FMC Corporation evaluates the thermal stability of the remaining hydrogen peroxide by heating it for 24 hr at 212°F. The procedure for this test is given in Reference 1. Although this procedure has only recently been included in FMC's standard compatibility-evaluation procedures, it has been employed by them for many years in evaluating the safety of storing hydrogen peroxide solutions.

3. Impact-Sensitivity Tests

Liquid and powdered materials (including solids which might yield finely divided particles in service such as a carbon bearing ring) are evaluated for sensitivity to impact when in intimate contact with H₂O₂ in various proportions. Impact sensitivity is determined by subjecting varying proportions of the material and H₂O₂ to the impact of a weight dropped from a specified height. In early tests a 1-kg-m (7-ft-lb) impact was used. Later a 3-kg-m (21-ft-lb) impact was provided. Now impacts up to 100 ft-lb (14.6 kg-m) may be attained. Most of the reported results are from tests at the 1- and 3-kg-m level of impact. The apparatus used for this test is a modified Bureau of Mines Liquid Explosive Impact Tester which may be used for testing at various temperatures up to 270°F. The procedures used by FMC Corporation are described in Reference 1.

In some tests, a small amount of wetting agent is added to the H₂O₂ to simulate the intimate contact which might be created by mechanical load such as might be found in pump packing or bearings. This practice, however, is not followed consistently.

4. Special Materials Tests

In general, the suitability of a material for an intended application is indicated by the laboratory tests. For example, an elastomer which becomes brittle during immersion in H₂O₂ is not suitable for the fabrication of O-rings for H₂O₂ service. However, some materials cannot be evaluated adequately by tests such as those described above; this is particularly true of coatings, protective clothing, and joint sealing compounds.

To overcome this weakness, FMC has developed special procedures for such materials. These procedures are outlined briefly below.

a. Protective Coating Tests

Protective coating materials are first tested by the standard compatibility procedure by coating them on standard-size sample strips. An additional test involves filling a coated steel cup with H₂O₂, inverting a second coated cup on top of the cup containing the liquid, and maintaining two such sets at 30°C (86°F) and 66°C (151°F) for one year and one week, respectively. A final laboratory test requires half-filling a coated 5-gal container with H₂O₂ and allowing the test container to stand at room temperature in the laboratory.

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or in a controlled-temperature room. Containers, 12 in. ID by 12 in. high, with a 2-in. vented opening in the top are recommended for a 12-mo test duration. Concentration of the H₂O₂ is determined initially and bimonthly thereafter for both the one-year cup test and the container test. A detailed procedure can be found in Reference 1.

b. Protective Clothing Materials Tests

In this test, the H₂O₂ is dropped on material that is both in the as-received and in the soiled condition. The soil used is KMnO₄ solution because this solution reacts violently with H₂O₂ and thus permits the determination of ignition and self-quenching properties for the materials. The special test procedure which has been developed for testing materials for use as protective clothing can be found in Reference 1.

c. Tests of Joint-Sealing Compounds

Joint-sealing compounds, in the set-up condition, which appear to be satisfactory by immersion and impact tests are further evaluated by making up sample seals and testing the seals in accordance with the special procedures given in Reference 1.

5. Experience

The final evaluation of a material for its suitability for an application involving contact with H₂O₂ is based on experience during use. In general, the recommendations of materials classification for H₂O₂ service are based on the results of laboratory tests and on practical experience. In a few instances, practical experience has shown results at variance with those of laboratory tests. Whenever this is the case, the greater consideration is given to practical experience and conclusions are drawn accordingly. Criteria established for laboratory tests are based as much as possible on correlations with experience resulting from placing the materials in service.

B. SERVICE CLASSIFICATIONS FOR MATERIALS

The results of laboratory evaluations and practical experience with various materials have shown that materials should be classified into categories according to their contemplated types of use. Thus all materials need not be suitable for indefinite periods of contact with H₂O₂. To facilitate selection, materials have been classified according to the types of applications for which they are suited.

In general, materials can be grouped into four classes for hydrogen-peroxide service.

1. Class 1 - Materials Satisfactory for Unrestricted Use With H₂O₂

Such service includes long-time contact with H₂O₂. Typical use: storage containers.

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2. Class 2 - Materials Satisfactory for Repeated Short-Time Contact with H₂O₂

Such materials are used for:

- a. Transient contact with H₂O₂ prior to storage of the H₂O₂,

or

- b. Limited contact with H₂O₂ prior to use. Such contact is not to exceed 4 hr at 160°F or 1 wk at 70°F. Typical use: (1) valves and pumps in H₂O₂ transfer lines, and (2) feed tanks.

3. Class 3 - Materials Which Should be Used Only for Short-Time Contact with H₂O₂

These materials might be used prior to a decomposition process or under similar conditions, and should be used only where neither Class 1 nor Class 2 materials would suffice. These materials can be used for repeated contact, but no one period should exceed 1 min at 160°F or 1 hr at 70°F prior to immediate use because contamination of the H₂O₂ may be otherwise sufficient to render it unsuitable for storage.

4. Class 4 - Materials not Recommended for Use with H₂O₂

These materials (1) cause excessive decomposition of H₂O₂ even on short-time contact, (2) are attached or suffer deterioration on contact, (3) yield corrosion or deterioration products which cause excessive decomposition of H₂O₂ on subsequent contact, or (4) form impact-sensitive mixtures with concentrated H₂O₂.

5. Clothing Materials

Clothing materials are classified as "suitable" or "unsuitable". Within the classification of "suitable", choices are made on the basis of resistance of the material to deterioration due to contact with the H₂O₂.

C. CRITERIA FOR EVALUATING TEST RESULTS

1. Compatibility, Thermability, and Impact Tests

The relevant criteria for classifying materials for H₂O₂ service on the basis of the tests outlined in Section A and from experience in service are summarized in Tab. 7. Since the classification system for H₂O₂ use is general for all constructional materials, the specific classifications are all-inclusive; limits for each class are given arbitrarily. For specific applications, more precise limits may be established.

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TABLE I

CRITERIA FOR CLASSIFICATION OF MATERIALS FOR H₂O₂ SERVICE
ON THE BASIS OF LABORATORY TESTS (REF. 1)

<u>Class</u>	<u>Material</u>	<u>Max. Amt. of AOL/wk(1)</u>		<u>Min. Stab. of H₂O₂</u>	<u>Other Criteria</u>
		<u>30°C</u>	<u>66°C</u>	<u>After Test, % (2)</u>	
1	Metals	0.2	5.0	95	No other effect on H ₂ O ₂ or material and non-impact sensitive to 3 kg-m impact at 212°F.
1	Plastics for drums, liners, diaphragms, and expulsion bladders	0.2	5.0	95	No other effect on H ₂ O ₂ or material and non-impact sensitive to 3 kg-m impact at 212°F.
1	For gaskets, tubing, O-rings, etc.	0.4	6.0	95	No other effect on H ₂ O ₂ or material and non-impact sensitive to 3 kg-m impact at 212°F.
1	Oils and greases	1.0	10.0	95	No other effect on H ₂ O ₂ or material and non-impact sensitive to 3 kg-m impact at 212°F.
2	Metals Stainless steel	6.0	80.0	90	No other effect on H ₂ O ₂ . Slight bronzing of the metal is acceptable, but no corrosion.
2	Plastics for O-rings and expulsion devices	6.0	80.0	90	No other effect on H ₂ O ₂ . Slight bleaching, swelling, embrittlement, or occasional blistering accepted. Non-impact sensitive to 3 kg-m impact at 212°F.

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TABLE I (cont.)

<u>Class</u>	<u>Material</u>	<u>Max. Amt. of AOL/wk(1)</u>	<u>Min. Stab. of H₂O₂</u>	<u>After Test, % (2)</u>	<u>Other Criteria</u>
		<u>30°C</u>	<u>65°C</u>		
2	Elastomers and bladder materials	6.5	95.0	90	No other effect on H ₂ O ₂ . Slight bleaching or loss of small amount of elasticity of the material accepted. Non-impact sensitive to 3 kg-m impact at 212°F.
2	Oils and greases	6.0	80.0	90	No other effect on H ₂ O ₂ . Non-impact sensitive to 3 kg-m impact at 212°F.
3	Metals	11.0	100/24 hr	15(3)	Bronzing and staining are acceptable, but not rusting or other corrosion products. Slight attack may be allowed.
3	Plastics	11.0	100/24 hr	15(3)	May become partially bleached, distorted, disintegrated, after 1 week on test. Non-impact sensitive to 3 kg-m impact at 212°F.
3	Oil and greases	11.0	100/24 hr	15(3)	Non-impact sensitive to 3 kg-m impact at 212°F. Excessive H ₂ O ₂ decomposition, approaching catalytic rate.
4	Metals				Metals - pitted and corroded during or after test.

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TABLE I (Concluded)

<u>Class</u>	<u>Material</u>	<u>Max. Amt. of AOL/wt_x(1)</u>		<u>Min. Stab.</u>	<u>Other Criteria</u>
		<u>30°C</u>	<u>65°C</u>	<u>of H₂O₂</u> <u>After Test, % (2)</u>	
4	Plastics				Plastics - disintegrated, burned, blistered.
	Elastomers				Elastomers - burned, swollen, dissolved, disintegrated, blistered, gummy, loss of elasticity.
	Oil and greases				Oils and greases - melted, disintegrated, burned. Any material which is impact-sensitive to 3 kg-m impact at 212°F.

(1) Active oxygen loss, wt%.

(2) The thermal stability of the H₂O₂ after exposure to the material. Defined as the percent of the H₂O₂ in the used sample which is not decomposed after heating 24 hr at 100°C (212°F).

(3) After 30°C test.

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The application of the criteria of Table I to the results of compatibility tests are subject to the following modifying considerations:

a. If there is any doubt as to whether a material should be in a given category, e.g., Class 1 or Class 2, the material is placed in the lower category.

b. If the results of practical experience are at variance with the results of laboratory tests, greater weight is given to practical experience.

c. The main distinction between Class 2 and Class 3 is their possible effect on the stability of H₂O₂. If there is any doubt as to whether the stability might be affected, the material is placed in Class 3. Slight deterioration of the material causing foreign matter to enter the H₂O₂ might cause decreased stability of the H₂O₂.

d. Numerical limits for the various Classes are approximate. Class-1 materials fall within rather narrow limits, whereas Class 2 materials fall within much broader limits. In general, the higher the active oxygen loss for a particular material, the less reproducible are the results.

Any material which is impact-sensitive when in contact with H₂O₂ in any proportion is considered a Class 4 material. The criteria of impact sensitivity of a material in contact with H₂O₂ is the incidence of any positive detonation on the basis of at least ten trials. A mixture which gives negative results in ten tests is considered to be tentatively non-impact sensitive unless later tests produce a positive result.

2. Protective Coating Tests

Criteria for the results of coating tests depend on the type of service contemplated; in other words, the coating must yield the Class of compatibility required for the application and must adhere tightly to the metal in the standard compatibility tests. Criteria for the cup or container tests have not been established, but it is believed that the coating should show no blisters or deterioration in contact with either the liquid-phase or vapor-phase H₂O₂ in one year at 30°C (66°F), one week at 65°C (151°F), or at the desired service temperature.

Coatings for splash resistance to be used as a protection for surfaces in H₂O₂ installations must not react violently with the H₂O₂ and must not blister in less than 24 hr at room temperature. Ease of application is also considered when analyzing results.

3. Protective Clothing Materials Tests

Clothing materials have been classified according to recommendations for their use. Criteria for such classification are:

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a. First Choice: The material does not burn on immersion or when drip-tested in as-received or soiled condition, and the fibers are not appreciably weakened after one month's immersion in 90% H₂O₂.

b. Second Choice: The material does not burn on immersion or when drip-tested in the as-received state, but it might be weakened considerably and burns only with difficulty in the soiled state.

c. Not Suitable: The material either causes excessive decomposition of the H₂O₂, burns, dissolves, or disintegrates in either the as-received or soiled state.

4. Joint Sealing Compound Tests

The primary consideration in selecting materials for use as joint sealing compounds with H₂O₂ is that mixtures of the compound with the H₂O₂ shall be non-impact sensitive to 3-kg-m impact at room temperature. The criteria for the impact test have been presented in Paragraph 1, above. Decomposition of the H₂O₂ in contact with the compound is of secondary importance; however, the compound must not be strongly catalytic to the decomposition of the H₂O₂. The compound may not be a Class 4 material.

The detailed test procedures outlined in Reference 1 were designed to evaluate the sealing and anti-seizing properties of compounds that show satisfactory compatibility with the H₂O₂. Exact criteria for these tests have not been established; however, it is recommended that the compound selected for a given application shall have yielded zero leakage in the two sealing tests up to a pressure 100 psig above the maximum required for the application and that in the anti-seize test there is no indication of reaction between the sealant and the metal, no galling of the threads upon disassembly, and/or no abnormal increase of torque required for disassembly over that applied upon assembling the test units.

D. RESULTS OF COMPATIBILITY EVALUATIONS AND ANODE EXPERIMENTS

The results of a large number of compatibility tests and a number of years of service experience have provided a comprehensive knowledge of the effects of hydrogen peroxide on many materials and the effects of those materials on hydrogen peroxide. The compatibility test results are presented in a series of tables. These tables and associated information derived from experience and miscellaneous tests are discussed in the following paragraphs.

1. Aluminum Alloys

The compatibility of a relatively large number of aluminum alloys with 90 and 90% hydrogen peroxide is summarized in Tables II and III, respectively. The major portion of the data presented in these tables is taken from the extensive IAC compilation on materials of construction,(1) however, it has been found that these data are in very good agreement with other published information. Wherever possible, the data from Reference 1 have been supplemented with data from other sources.

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TABLE II
COMPATIBILITY OF 90% H₂O₂ WITH ALUMINUM ALLOYS*

Material	Effect of Material on H ₂ O ₂			Effect of H ₂ O ₂ on Material	Material Source	Comments
	Wt% AlL (1)	Wt% AlL (2)	Stability (2) After Test (2)			
Strength Alloys						
1060	1	0.3	2.5	98.9	None	Alcos
1100	1(3)	0.4	3.0	-	None	Alcos
1150	1	0.4	1.5	98.9	None	Alcos
1260	1	-	1.5	98.8	None	Alcos
Pretreated (4)	1	-	0.7-0.8 (5)	98	None	Alcos
Pretreated (5)	1	-	2.5 (5)	98	None	Alcos
2	-	-	100	-	None	Not recommended
301;	4	-	11.0	-	None	Alcos
21-4	3	-	16.4	-	None	Not recommended
303	2	-	13.8	94.4	None	Alcos
4043	2	-	52	98.8	None	Alcos
5052	2	-	8.3	-	None	Alcos
5054	2	-	-	-	None	Ircos
9051	2	1.5	13.1	-	None	Alcos
9255	2	-	-	-	None	Tubing, pipe
5234	1(3)	-	0.3	98	None	Alcos
5652-0	1(3)	-	5.0	98.4	None	Alcos
6061	2	-	4.8	98.7	None (7)	Alcos

³ Reference I unless otherwise noted.

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TABLE IV (cont.)

Material	Classi- fication	Effect of Material on H ₂ O ₂			Effect of H ₂ O ₂ on Material	Ma- terial source	Comments
		wt% H ₂ O ₂ @ 30°C	wt% H ₂ O ₂ @ 35°C	Stability After 1 hr (2)			
<u>Wrought Alloys</u>							
6063	Sheet	1	-	1.	98	Dulls finish	Reynolds
	Tubing	1	-	3.3	97.4	Slight-dulling	Reynolds
	Hard Coat	2	-	3.1	98	Bleaching and Spotting	Reynolds
6363	2	-	-	7.6	96.2	None	Alcoa
7072	1(3)	-	-	2.1	-	None	Alcoa
7075	4	-	-	100	0	None	Kaiser
Casting Alloys							
403	2(8)	-	-	2	95.4	None (7)	0.P.W. Corp. (Kear Lok)
43	2	-	-	-	-	None	Used as pump impeller and in quick-disconnect flanges
150	2	-	-	28.7	-	None	Based on Reference 2
21b3	2	-	-	50.0	-	Stained	Limited use
21bP	2	-	-	35.9	-	None	Kaiser
21B	4	-	-	100	0	Corroded	Alcoa
355	4	-	-	-	-	None	Not recommended
355P	4	-	-	-	-	None	Not recommended
356P	2	-	-	100	0	None	Based on Reference 2
8356	1	-	-	50	-	None	Alcoa
A360	3	-	-	2.8	98.0	None	Pumps, valves, housings
750	4	-	-	96.8	-	None	Alcoa
		-	-	100	-	None	Not recommended
		-	-	-	-	Alcoa	Not recommended

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TABLE II (cont.)

Material	Classification	Effect of Material on H ₂ O ₂			Effect of H ₂ O ₂ on Material	Material Source	Comments
		Wt% AOL @ 30°C	Wt% AOL @ 65°C	Stability (2) After Test (2)			
Cutting Alloys							
A750	4	-	100(9)	-	None	Alcoa	Not recommended
B750	4	-	100(9)	-	None	Alcoa	Not recommended
Chromatic Acid Anodized							
2024	4	-	100	-	None	Colonial Alloy	H ₂ SO ₄ anodized is better
5052	2	-	11.0	-	None	Colonial Alloy	H ₂ SO ₄ anodized is better
6061	3	-	15.5	-	None	Colonial Alloy	H ₂ SO ₄ anodized is better
H₂SO₄ Anodized							
2017	3	-	23.3	-	None	Alcoa	Limited service life (1 to 2 yr)
2024	3	-	15.0	-	None	Alcoa	Limited service life (1 to 2 yr)
5052	2	-	5.0	-	None	Alcoa	Limited service life (1 to 2 yr)
6061	2	1.3	4.1	-	None	Alcoa	Limited service life (1 to 2 yr)
45% HNO ₃ Pass.	2	-	2.4	89.4	None	Alcoa	Limited service life (1 to 2 yr)
Detergent wash	2	-	4.5	90.8	None	(Keystone Chromium)	Limited service life (1 to 2 yr)

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TABLE II (cont.)

Material	Classifi- cation	Effect of Material on H ₂ O ₂			Effect of H ₂ O ₂ on Material	Material Source	Comments
		% Mo @ 30°C	% Mo @ 66°C	Stability (2) After Test (2)			
<u>H₂SO₄ Anodized 6061</u>							
WFIA Pass.	2	-	3.6	87.2	None	(Keystone Chromium)	Limited service life (1 to 2 yr)
Hard coat	3	-	23-42	50-70	None	Woodward- Governor Coatings and Stolle Corp.	Must be checked before using

NOTES:

- (1) Active oxygen loss, weight percent.
- (2) The thermal stability of the hydrogen peroxide after exposure to the material of construction. Defined as the percent of the H₂O₂ in the used sample which is not decomposed after heating at 100°C for 24 hr.
- (3) Previously considered Class 2.
- (4) Sample preheated with 90% H₂O₂ for 24 hr at 66°C.
- (5) Test temperature 73.9°C (165°F)
- (6) Sample preheated with Alcos treating solution #1 for 48 hr at room temperature.
- (7) Field experience shows this alloy to be subject to corrosion if not protected by anodizing
- (8) Previously considered Class 4.
- (9) 100% loss in 3 days.

TABLE IIICOMPATIBILITY OF 98% H₂O₂ WITH ALUMINUM ALLOYS (REF. 1)

<u>Material</u>	<u>Classification</u>	<u>Effect of Sample on 98% wt% H₂O₂, AOL(1) %/mo330°C</u>	<u>H₂O₂ Stability After Test (4) %/wt%66°C</u>	<u>Effect on Sample</u>	<u>Material Source</u>	<u>Comments</u>
1060	1	1.5	98%	None	Alcoa	Storage tank
1160	1	1.5	98%	None	Alcoa	Storage tank
1260	1	2.1 (2)	98%	None	Alcoa	Storage tank
1260	1	1.2 (3)	98%	None	Alcoa	Storage tank
2024	4	100.0	--	None	Colonial Alloys	Not recommended
5052	1	2.6	--	None	Alcoa	Storage vessels
5652-0	1	5.2	98.4%	None	Alcoa	Storage vessels
7072	1	4.1	--	None	Alcoa	Storage vessels
B-356	1	3.9	98%	None	Alcoa	For casting use

NOTES:

- (1) Active oxygen loss, wt%
- (2) Test temperature 165°F/week pretreated 90% H₂O₂ 24 hr at 66°C
- (3) Test temperature 165°F/week, pretreated with Alcoa treating solution 1 48 hr, room temperature
- (4) See footnote 2, Table II

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The results of compatibility tests presented in Tables II and III indicate there are several aluminum alloys which meet the stringent requirements of Class 1 materials. Of these, controlled-copper-content aluminum alloys (1060, 1160, and 1260) and low-copper-content 5254-0 and 5254 H-34 aluminum alloys have given excellent service. The low copper content 1060 aluminum has been used most frequently in storage-tank fabrication and piping. Minimum corrosion has been experienced with this alloy. Because low copper content 1060 aluminum is not always readily available, 1260 low copper content aluminum is also being employed.

Where higher mechanical strength is required, aluminum alloys 5652 and 5254, both with copper content controlled at less than 0.06 wt% may be used. Tank cars of 4000 and 8000 gal capacity fabricated from these alloys have given satisfactory service with all concentrations of H_2O_2 since 1952. The 5254 alloy used in these tank cars was tempered to various conditions, including O, F and H-32.

Wrought alloy 6061 has been employed in H_2O_2 service because of its high strength in the T-6 temper and its good availability in bar stock form. Despite its satisfactory results in compatibility test, alloy 6061 is usually not recommended unless there is no other alloy available to meet the requirements. This alloy is more susceptible to corrosion in intermittent wetting applications than the other aluminum alloys used to handle H_2O_2 . To overcome this weakness, sulfuric-acid anodization followed by a one-hour boiling-water seal without dye is usually recommended if alloy 6061 is to be used. This alloy is not normally recommended for piping; however, sulphuric-acid anodized small-diameter tubes and tanks have given good service in power systems.

Wrought alloy 6363, which is a recent product with controlled copper content, shows excellent Class 2 compatibility with 90% H_2O_2 in laboratory tests; however, there is no experience information at this time.

The high-strength structural alloys such as 2014, 2017, and 2024 are unsuitable for service with H_2O_2 because of corrosion and because of the high rate of H_2O_2 decomposition associated with their use. Although compatibility is improved by sulfuric-acid anodization, only Class 3 service is indicated by laboratory results. There is no experience on the use of anodized alloys to indicate whether or not the anodized surface can be maintained satisfactorily.

Aluminum casting alloys 43 and 356 have been used successfully for pump and valve bodies for many years, although some corrosion generally does occur. The controlled copper casting alloy B-356 has indicated Class 1 compatibility in laboratory tests with 90% and 90% H_2O_2 , and satisfactory service experience has resulted when using these H_2O_2 concentrations.

Some testing has been carried out on hard-coated aluminum. Laboratory test results of 10, 20, and 30 min penetration on aluminum alloy 6061 indicate Class 3 compatibility with H_2O_2 . Use experience is very limited.

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Experience is also needed to determine the resistance of hard-coated aluminum to corrosion in service with intermittent wetting.

2. Stainless Steels

The results of compatibility tests with various stainless steels and 90 and 98% hydrogen peroxide are summarized in Tables IV and V, respectively. From these tables it is apparent that no Class 1 stainless steels have been found, but that a fairly large number of Class 2 materials are known. In general, the wrought or forged 300-series stainless-steel alloys with proper passivation are suitable for Class 2 service with hydrogen peroxide. Cast stainless steel is generally unsatisfactory for H₂O₂ service unless special casting techniques are followed. The 400-series stainless steels rust and cause excessive H₂O₂ decomposition.

301 stainless steel is normally rated as a Class 3 material; however, cryogenically prestrained 301 is rated as Class 2 and almost Class 1. The prestrained material is of particular interest because of its very high yield and tensile strengths (260,000 and 280,000 psi, respectively). Stainless steel 302 is reported to have an excellent service record with 98% H₂O₂. The extra-low-carbon stainless steel (304 ELC) has been shown to be an excellent H₂O₂ tank material. This material shows excellent compatibility with H₂O₂ at room temperature and elevated temperatures.

Hydrogen peroxide test tanks are usually fabricated of 347 stainless steel which contains columbium as a welding stabilizer. More than fifteen years of service have been obtained with such tanks handling 90 and 98% H₂O₂. 321 stainless steel is used in some systems; however, the titanium welding stabilizers have a slight catalytic effect on H₂O₂.

The AISI 400 series stainless steels, whether annealed or in the heat-treated form (40-58-Rc), will rust if the surface finish is greater than 10 rms.

An extensive amount of testing has been carried out on precipitation-hardened stainless-steel alloys such as AM-350 and 17-7 PH alloys. The AM-350 material has given excellent service in flight vehicles; however, the hardness of the material must be less than 42 Rc or there is an increase in H₂O₂ decomposition and metal rusting develops.

The 17-7 PH material has proven very successful with 76% H₂O₂ and moderately successful with 90% H₂O₂; however, a special passivation treatment is required to achieve a Class 2 rating for this material. Surface-finishing of the sample with 120-grit abrasive compound is found to be effective in improving the compatibility of this alloy.

Aerojet work⁽³⁾ has indicated that the manner of passivation has a direct effect on the compatibility of hot 98% H₂O₂ (270°F) with the stainless steels. SS 304 indicated moderately good short-term serviceability at 270°F when passivated by one procedure; however, when an alternative recommended passivation procedure was employed, the 304 SS was completely

TABLE IV
COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH STAINLESS-STEEL ALLOYS (REF 1)

Material No.	Classification	Effect of Material on H ₂ O ₂			Material Source	Comments
		Effect upon H ₂ O ₂ After Test (1)	Stability (2) After Test	Effect upon Sample		
302	2	-	19.0	--	Bronzed	Bruce Mueller
303	3	-	20.0	57	Slight stain	Portland Copper & Tin Works
311 (tempered and pretrained)	2	-	4.2	96	Slight stain	Arco Portland Corp.
312	2	-	21.0	99.0	Bronzed	Whitehead
314	2	-	40.0	--	Bronzed	Allegheny-Ludlum
316 ELC	2	-	50.6	--	Bronzed	Allegheny-Ludlum
319	2	-	54.2	--	Bronzed	Carnegie
320	2	-	37.1	--	Bronzed	High-acid tank, H ₂ O ₂ comp. batch
316	2	-	19.8	--	Bronzed	Republic
316 ELC	2	-	20.5	--	--	Arco Steel
317	2	-	36.0	--	Bronzed	Test vessels, machined parts
318	2	-	69.4	--	Bronzed	Allegheny-Ludlum
319	3	19.1	62.3	--	Bronzed	Allegheny-Ludlum
319	3	19.1	75.3	--	Bronzed	Union Steel Co.
321	2	-	37.0	--	Bronzed	Union Steel Co.
322	2	-	30.0	--	Bronzed	Carnegie
329	2	-	5.5	--	Dull finish	Hydromatic, Inc.
						Test treatable. Do not exceed 10 to 10.5 m.s. fluid, machined parts

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TABLE IV (cont.)

Material	Classi- fication	Effect of Material on N_2O_2				Material Source	Comments
		\$720 @ 15°C wt. act. (%)	\$720 @ 65°C wt. act. (%)	Stability (?)	Effect upon Sample		
329	4	--	100	--	Bronzed	Craze Valve Company	Not recommended, rough finish
347	2	--	57	--	Bronzed	Carnegie	Gas generators, thrust motors
AM 350 Heat Treat I	3	--	7.8	90	Heavy bronzing	All-Albany-Ledum	High-pressure vessels, 160,000 psi yield
AM 350 Heat Treat II	4	--	18.6	31	Very heavy bronzing	All-Albany-Ledum	High-pressure vessels, as above #2
AM 355	3	--	78.9	--	Bronzed	All-Albany-Ledum	High-pressure vessels
b10	4	--	91.4	16.6	Rusted	Diesel Eng.	To be avoided
b16	4	--	100	0	Rusted	Beidle	To be avoided
b20	4	--	100/18 hr	0	Rusted	Lee Company	To be avoided
b30	4	--	78.4	37.5	Rusted	All-Albany-Ledum	To be avoided
b31	4	--	100	0	Rusted	--	To be avoided
b40	4	--	100/2 hr	0	Rusted	Beidle	To be avoided
Mo C, 56-59 Re, 10-20 NiS	3(3)	2.3	100/13 hr	--	Slight bronzing	Beidle	See note (b)
Mo C, Molybdenum, Re 50	3(3)	5.2	100/48 hr	--	Slight stain	Beidle	See note (b)
b53	4	--	100	0	Rusted	--	To be avoided
b46	4	--	100	0	Rusted	All-Albany Ledum	To be avoided
17.7 Ph, 37-45 Re, 120 grit surface finish, special passivation	2	--	20	--	Bronze in vapor phase and interface. Very slight bronzing in liquid.	Armco Steel	This alloy more suitable for use with lower than 90% N_2O_2 concentrations. High-pressure-system components.
17.7 Ph, 37 to 45 Re welded, 120-grit surface finish, special passivation	2	--	20	--	Bronze in vapor phase & interface. Very slight bronzing in liquid.	Armco Steel	This alloy more suitable for use with lower than 90% N_2O_2 concentrations. High-pressure-system components.

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TABLE IV (cont.)

Material	Clean- ing/ Electro- polish ing	Effect of Material on H_2O_2			Material Source	Comments
		wt. % H_2O_2	wt. % at 30°C	Stability (2) After Test (2)		
17-7 PH, 6% Ni, pickled to prevent intergranular attack, Special passivation.	3	--	100	--	Same	Arco Steel Base
17-7 PH, 6% Ni, grit surface finish, electropolished	3	--	57.5	--	Same	Arco Steel Base
17-7 PH, 6% Ni, 120- grit surface finish, buried, special passivation	2	--	22.0	--	Same	Arco Steel Base
17-7 PH (unhardened)	2	--	43.0	--	Bronzed	Arco Steel Base
17-4 PH	3	--	90-100	--	Bronzed heavily	Arco Steel Not recommended
Carpenter 20	3	--	1.0	--	Bronzed	Carpenter Steel
Durimet 20	3	--	1.0	--	Bronzed	Durimet Company
Hesco-O-Screws	2	--	.7	--	None	Hesco Valve & Mach. Machine parts
Malin-Milwaukee	2	--	.25	--	None	Malin & Company Springs
15-7 Mo	3	--	.34	20	Bronzed heavily	Air Research Mfg. Co. Machine parts, gas generators

(1) Active oxygen loss, wt.
 (2) See Footnote 2, Table II
 (3) Surface finish must be better than 10 rms.
 (4) Additional test data are available from MC Corp. for samples with special surface treatments in contact with stabilized H_2O_2 .

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TABLE V
COMPATIBILITY OF 98% HYDROGEN PEROXIDE WITH STAINLESS-STEEL ALLOYS (REF. 1)

Material	Classification	Effect of Material on H ₂ O ₂			Effect on Sample	Material Source	Comments
		wt % loss (1) at 50°C	Stability at 50°C	After Test (2)			
301	2	--	8.7	95%	Bronzed	Arts	High pressure tanks
302	2	Excellent service record			Bronzed	Portland	Various
304	2	--	12.0	--	Bronzed	Suppl.	Tubing, machined parts
316	2	--	53.0	--	Bronzed	Alliagay Filles Republic	Tubing, machined components
329	3	--	30.0	--	Bronzed	Machined	components
347	2	Excellent service record			Bronzed	Crane Valve	Machined components
347	2	--	13.2	92%	Sl. bronzed	Pressure vessels	Pressure vessels
15-7 No. 3	3	--	21.0	--	H. bronzed	Air Research	Machined parts

* Ecco M3 Grade 98% H₂O₂ used

1:

- (1) Active oxygen loss, wt %
- (2) See footnote 2, Table II

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incompatible. It is therefore concluded that present compatibility data are insufficient to recommend a material for very high-temperature peroxide service. Additional tests should be made on materials intended for high-temperature usage.

3. Other Metals

The results of compatibility tests with various pure metals are summarized in Table VI and with miscellaneous alloys in Table VII.

Many pure metals have been evaluated, but few have been found suitable for H_2O_2 service. Silicon, tantalum, tin, and zirconium are exceptions. Of these, tin has been utilized to the greatest extent, mostly for gaskets and as a solder for stainless steel.

Most other metallic elements have catalytic action in contact with H_2O_2 . This is especially true of silver, lead, cobalt, and platinum. Iron after exposure forms iron oxide (rust) which is catalytic. Titanium and zinc are severely attacked by the H_2O_2 .

A few alloys have shown suitability for Class 3 service and might be made suitable for Class 2 service with other passivation techniques; however, little has been done on these alloys beyond application of standard procedures.

Unfortunately, there are no metals of extreme hardness that have shown suitability for even Class 3 service except the 10-rms-finish 410C stainless steel (56 to 58 Re) and the hard bearing chrome plating (53 to 70 Re). Kanegin electroless nickel plating over hard surfaces has shown promise.

The compatibility of Inconel 718, Hastalloy C, and Hastalloy X has been tested at Aerojet-General(3) with 5% H_2O_2 at 270°F. The two former materials were slightly bronzed and the concentration of H_2O_2 decreased about 10% in 1 hr. With the latter material, there was little or no apparent change in the alloy, but the H_2O_2 concentration decreased to about 45% in 1 hr.

4. Plastics and Rubbers

The results of compatibility tests with numerous plastics and rubbers are summarized in Tables VIII, IX, X, XI, XII, and XIII.

Since plastics and rubber compounds are organic substances, the compatibility with hydrogen peroxide varies considerably, and even those materials which have shown excellent compatibility with concentrated H_2O_2 , both in the laboratory and in use, may be suspect when new conditions are met that have not been encountered or simulated previously. Conditions that may lead to reaction between a plastic material and H_2O_2 are extremely varied and difficult to predict or to evaluate in the laboratory. However one generalization may be made: The combination of concentrated hydrogen peroxide, organic materials and heat, either from an external source or from H_2O_2 decomposition, may lead to an explosive reaction and must not be allowed to develop.

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TABLE VI
COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH PURE METALS (REF. 1 & 2)

Material	Classification	Effect of Sample on H ₂ O ₂			Source of Material
		wt% AOL(1) /wk	at 65°C	After Test(2)	
Aluminum (3)	-	---	---	---	---
Beryllium	4	100	0	Pitted	---
Cadmium	4	100	0	Pitted	---
Gold	4	100	0	Pitted	---
Chromium	4	100	0	Very slightly soluble	Keraus-Ceram
Cobalt	4	100	0	Slightly soluble	---
Copper	4	100	0	Very slightly soluble	---
Gold	4	100	0	None	---
Iron	4	100	0	Heated	---
Lead	4	100	0	Dissolved	---
Manganese	4	100	0	slightly soluble	---
Mercury	4	100	0	None	---
Molybdenum	4	100	0	Violet decom. of H ₂ O ₂	General Electric Co.
Nickel	4	100	0	Dissolved	---
Patinum	4	100	0	None	---
Silicon	2	3.5	97	Sl. surface dulling	---
Silver	4	100	0	Attacked	---
Sodium	4	100	0	Violent decom. and flame	---
Tantalum	4	---	---	None	Pansteel Met. Corp.
Tin - C.P.	2	28.7	---	None	Fisher Chem. Co.
Titanium	4	100	0	Pitted	East-Gru Titanium Inc.
Tungsten	4	100	0	Dissolved	---
Zinc	4	100	0	Pitted	---
Zirconium	1	3.2	---	None	National Lead Co.

(1) Active oxygen loss, wt%

(2) See footnote 2, Table II

(3) See Tables II and III

(4) Based on service experience

TABLE VII

COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH MISCELLANEOUS ALLOYS (REF. 1)

Material	Classification	Effect of Sample on H ₂ O ₂		Effect of H ₂ O ₂ on Sample	Source of Material
		wts AOL(1)/wk at 65°C	Stability(2) After Test(2)		
Aluminum oxide Flame-plated on Armco 17-7 PH	4	100	---	One rust spot	Lands Co.
Polymer-bronze					
Copper-nickel		100	None		
Copper-tin		100	Pitted		Electro-Alloys Div.
Copper		100	None		Durimet
Dow Metal JA		100	None		Dow Chemical Co.
Dow Metal MA		100	None		Dow Chemical Co.
Duriron (cast)		100	None		Duriron
Laticoy		100	Bronzed		Elgin Watch Co.
Ferric "O"		100	None		Farmsteel Met. Corp.
L775		90.0	None		Carbide & Carbon
Instellooy "B"		100/15 hr	None		Lyman-Satellite Corp.
Instellooy "C"		100/15 hr	None		Lyman-Satellite Corp.
Instellooy "D"		100/3 hr	Bronzed		Lyman-Satellite Corp.
Instellooy		65-72.7	Bronzed		Lyman-Satellite Corp.
Lyman-Satellite		100/1.5 hr	None		Lyman-Satellite Corp.
13		100/3 hr	None		Lyman-Satellite Corp.
15		100/3 hr	None		Lyman-Satellite Corp.
12		100/1 hr	Bronzed		Lyman-Satellite Corp.
105		100/1 hr	Bronzed		Lyman-Satellite Corp.
C1772-3		100	0		Lyman-Satellite Corp.
C537-3		97.8	Bronzed		Lyman-Satellite Corp.
E17-3		100	Bronzed		Lyman-Satellite Corp.
13		100	Bronzed		Lyman-Satellite Corp.
15		100	Bronzed		Lyman-Satellite Corp.
11316-3		100	Bronzed		Lyman-Satellite Corp.
11316-3		25.1	Bronzed		Lyman-Satellite Corp.
11116-6		100	Bronzed		Lyman-Satellite Corp.
Inconel "K" (full hard)		100	Bronzed		Illius Corp.
Inconel Plated		100/72 hr	Irons		Internat. Nickel Corp.
14M steel		51-82	Discolored		Internat. Nickel Corp.
	3	0.6-0.9(3)	89-95		Keystone Chemical
	2		94-97		Keystone Chemical

TABLE VII (Concluded)

Material	Classification	Effect of Sample on H ₂ O ₂			Source of Material
		wt% AOL (1) / hr	Stability at 66°C	After Test (2)	
Hemisetal K-138	4	100	0	0	Hemisetal, Inc.
Hemisetal K-3H	4	100	0	0	Hemisetal, Inc.
Hemisetal K-501	4	100	0	0	Hemisetal, Inc.
Hemisetal K-H	4	100	0	0	Hemisetal, Inc.
Steel	4	100	0	0	Internat. Nickel Corp.
Hastelloy B-155	4	100/16 hr	0	Rusted	Haynes-Stellite Corp.
HC-1 Incast 2107	4	100	-	None	Internat. Nickel Corp.
Monel	3	45.3	-	None	Westinghouse
Monel	3	100	-	None	Westinghouse
Monel	3	100	0	Bronzed	Mitsubishi
Coral, mild	4	100	0	Rusted	Commercial
Cast-Alloy, S-583	4	100	0	None	Allegheny Ludlum
Cast-Alloy, S-590	4	100	0	None	Allegheny Ludlum
Monel	4	100	0	None	Allegheny Ludlum
Titanium 16-25-6	3	50	-	SL. bronzing	Titanium Roller Eng. Co.
22-n-Plated mild	2	0.6(3)	96.7	SL. staining severely discolored	Keystone Carbium
Steel	4	100	0	Bronzed	Crucible Steel Co.
Titanium, Ti20VCA	4	100	0	None	Union Carbide
ECI-Star "J" Metal	4	100/4 hr	-	None	Utility Excel Foundry
Utility 3	4	100/2 hr	-	None	Utility Excel Foundry
Utility 20	4	100/2 hr	-	None	Utility Excel Foundry
Utility H	4	100/3 hr	-	None	Utility Excel Foundry
Utility EH	4	100/2 hr	-	None	Worthington Corp.
Korthite	3	100	-	None	Universal-Cyclops
19-9 HL	3	100	-	Bronzed	Steel

(1) Active oxygen loss, weight percent

(2) See footnote 2, Table II

(3) Room temperature tests rather than 66°C

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TABLE VIII
**COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH POLYETHYLENE AND HALOCHEMATED
 POLYETHYLENE TYPES OF PLASTICS***

Material	Classification	Effect of NaCl on H ₂ O ₂			Effect of H ₂ O ₂ on Material	Material Source	Comments
		wt % ADJ (1) H ₂ O ₂ @ 30°C	wt % ADJ (1) H ₂ O ₂ @ 60°C	Stability Factor (2)			
Aclar	1	0.6	1.2(3)	99	None	Allied Chemical	Bladder material, drum liners Not recommended for 120°F use
70 Duro P-509	4	-	10.2	78.5	Severely blistered	Belmont Packing
Injay Rubber	4	-	-	-	Severely blistered	Huber O-Ring Co.	Not recommended
Monel Propylene (10-L-60)	4	-	42	0	Blistered	Honeywell Chem. Co.
Polyrene P557-167 (Viton A, 116 glass)	3	-	-	-	Surface attack and moderate blistering (1 hr @ 151°F)	Dupont	Based on Ref. 2
Polyrene P557-168 (Viton A, Neoron)	2	-	-	-	Moderate surface attack (1 hr @ 151°F)	Dupont	Based on Ref. 2
Thiokol 2140	1	1.0 to 1.1	-	98	None	Min. Mining & Mfg.	O-rings, seals, bladders
	1	-	0.3	99	None (1 day @ 151°F)	Min. Mining & Mfg.	Not rec. at 151°F
	2	-	1.1	98.5	Very slight blistering	Min. Mining & Mfg.
	4	-	-	96	Blistered	Seals Eastern Inc.
Fluoroflex T-TP1001 (black)	1	-	3.6	-	None	Resistoflex Corp.	High-pressure hose
Fluoroflex T-TP1001 (black)	2	-	6.7	-	None	Resistoflex Corp.	High-pressure hose
Fluran B-4100	3	48.3	0	Partially bleached	U.S. Stoneware	
Fluorostent	3	38.8	33.1	None	Polymer Corp.	
Flurane CR9070 Black	4	-	-	None	Whitro Assoc.	
Halocore	2	4.6	-	None	Fab Lab Supplies	
Hypalon S-2	4	100	-	Sample destroyed (1 hr)	Dupont	
Hypalon Gasket	4	78.2	2	Severe attack	Metal Hose & Tubing	Unsatisfactory	
Hypalon, grey V-54-%, grey V-56-%, and black V-163-4	4	100	-	Blistered and swollen	Raybestos-Manhattan	Unsatisfactory (Ref. 1 and 2)	
Nylon O-ring (CCR 90-1)	3	-	19	71.4	Moderate surface attack	Goben Rubber Co.	Not recommended
Irratene 101 (irradiated polyethylene)	2	-	3.0	96.6	None at room temp; can ignite at > 160°F	General Electric Co.	Seals and gaskets
Met-F (unplasticized)	1	-	3.5(3)	98	None	Min. Mining & Mfg.	Gaskets, seals, seats
Met-F 800	1	-	2.9(3)	-	None	Min. Mining & Mfg.	High comp. service, seals, seats

* Reference 1 unless otherwise noted.

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TABLE VIII (cont.)

Material	Classification	Effect of Mat'l. on H ₂ O ₂			Effect of H ₂ O ₂ on Material (2)	Material Source	Comments
		H ₂ O ₂ @ 30°C	wt % ADI (1)	Stability @ 65°C			
Kel-F 800 (lot 5609)	1	-	4.5	-	97.4	Gaskets, seals, seats	
Kel-F 820 (lot 56028)	2	-	9.0	-	93.2	Gaskets, seals, seats	
Kel-F 3700 gum	3	-	8.8	-	-	Gaskets, seals, seats	
50% Kel-F 3700,	2	-	3.6	-	-	Gaskets, seals, seats	
50% Kel-F 800,	2	-	26.3	97.0	-	Gaskets, seals, seats	
Kel-F 5550 (unpigmented	2	-	18.5	95.7	Slightly tacky	Gaskets, seals, seats	
Kel-F 5550 gum	3	-	19	--	Blistered and distorted	Not recommended	
Kel-F 5550-121	2	-	9	--	Bleached	Use other compounds	
Kel-F 5500-61	2	-	3.6	97.7	None	Gaskets, seals, seats	
50% Kel-F 5500, 50%	2	-	3.2	94.2	Slight blistering	Gaskets, seals, seats	
Kel-F 800	2	-	6.4	95.5	Moderate surface attack, slightly sticky	D-rings, gaskets	
Kel-F O-Ring (Cord. 7761-70)	2	-	5.1	97	Very slight bleaching	Explosion bladders	
Kel-F D 316	2	-	9.0	94	Very slight bleaching	Explosion bladders	
Kel-F D 395	2	-	-	-	-	Based on Ref. 2	
Kel-F Elastomer 5160	2	-	1.1	-	-	Seals	
Kynar - vinylidene	2	-	3.8	91	Slight bleaching	Firestone Rubber Minn. Mining & Mfg. Nitro Assoc.	
Maligon P 73-223	2	-	1.9	99	Bleached and slightly distorted	Tube Turns, Inc.	
Quail (Viton A)	1	0.7	-	96	Bleached	Voplex	
Quail (Viton A)	2	-	1.3	-	None	Plastic components David Clark Co.	
Penton 9215	2	-	1.4	96	Very slight blistering at 151°F Bleached from olive	David Clark Co. Hercules Powder	
Penton 9215	2	-	7.9 (4)	95	-	Possibly plastic pipe and tube use	
Polyester M-85	4	-	4.0	97	Discolored, swollen	Whitro Assoc.	
Polyethylene-	4	-	6.6	90	Snaps because brittle	Kem-E-Quip Corp.	
porous vinyl	3	-	7.4	84	Bleached slightly	Cebot Corp.	
Polyethylene, black	3	-	1.0	95	None at R.T., can detonate with H ₂ O ₂ if heated	DuPont	Not recommended except for R.T. use
Polyethylene	2	-	2.9	98	None	General Electric Co.	Not recommended for high temp.
Polyethylene N.D. (3)	1	-	-	-	-	Plax Corp.	Based on Ref. 2
Polyethylene HD-2	4	-	-	-	-	-	-

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TABLE VIII (cont.)

Material	Classification	Effect of Mat'1. on H ₂ O ₂		Effect of H ₂ O ₂ on Material	Material Source	Comments
		vt & AOL (1) Vec. @ 30°C A.R. @ 55°C	Stability (2) After Test			
Polyethylene Foam	-	-	-	No apparent swelling but some bleaching (1 day @ R.T.)	Dow Chemical Co.	Based on Ref. 4
Polyene E-51 (3)	2	-	98.1	None	Pall Flit. Corp.	Filter media
Polypropylene (black)	2	-	98.3	S. bleaching	Poly Turis, Inc.	Tube and pipe fittings
Scotch Pack 2045	1	1.7(4)	98.1	None	Minn. Mining & Mfg.	Film material
Scotch Pack 49410	1	1.1(4)	98	None	Minn. Mining & Mfg.	Various uses
Teflon (White)	1	2.8	95	None	DuPont	Not effectively heat-sealable
Teflon 10X FEP	1	2.6	98.3	None	DuPont	
Fluorocarbon	-	-	-	None	DuPont	
Teflon Seal (isolated 100%)	1	0.56(6)	98	None	DuPont	
Teflon Tape	1	0.2	98	None	DuPont	Thread compound
Teflon w/edged	1	2.8	98	None	Seals, bladders	
Teflon + Fluorostat	2	2.0	98	None	Potter Aeronaut.	Bearing for turbine
Teflon PTFE cell (5)	1	1	95	None	Chemengineers, Inc.	Emulsion bladder
Teflon PTFE cell (6)	3	3.3	96	None	Dielectricx Corp.	Emulsion bladder
Teflon TFE (5)	2	4.0	97	V. sl. bleaching	Chemengineers, Inc.	Emulsion bladder
Teflon TFE (3)	1	3.6	97.5	None	DuPont	Emulsion bladder
Vicoce 1B5	2	1.5	98	None	North American Av.	Bladder material
Vicoce 1B5	2	2.8	99	Sl. bleaching	North American Av.	Excellent elastomer
Vicoce 1B5	2	0.1	99	V. sl. bleaching	North American Av.	Bladder material
Vicoce 31-2	2	0.6	99	None	North American Av.	Emulsion bladder
Vinyldene-Fluoride	1	1.2	98	None	Pall Flit Corp.	Filter media
Vinyldene-Fluoride	2	0.5	97	Two out of three samples showed low stability	Pall Flit Corp.	Filter media
Viton A (271-7) (7)	2	-	-	Good service to 3 days at 151°F	Parker Hannifin	O-rings, seals, diaphragms
Viton A (271-7)	4	-	-	Blisters after 3 days at 151°F		
Viton A (271-7)	2	-	-	None	Seals, Inc.	O-rings
Viton A (271-7)	2	-	-	None	R.P. Goodyear	O-rings, seals
Viton A (271-7)	3	-	-	Blistered and swelled	Hewitt Robbins	Not recommended for service above 120°F
Viton A-9070	2	-	-	None	Nichols Eng'r Co.	O-rings, bladder
Viton A-9070	2	-	-	No noticeable attack (1 day @ R.T.), severe attack in 1 day	Preston Rubber	Based on Ref. 5
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TABLE VII (cont.)

Material	Classification Ref. No.	Effect of Matt'l. on H_2O_2		Stability (2) After Test (2)	Effect of H_2O_2 on Material	Material Source	Comments
		wt. % Acid (1)	temp. 95°C				
Viton A-SE 270-70	-	-	-	-	No noticeable attack (1 day @ 150°F), minor attack in 3 days @ 200°F	Stillman Rubber Co.	Based on Ref. 5
Viton A-SE-251-T	-	-	-	-	No noticeable attack (1 day @ 150°F), minor attack in 1 day @ 200°F	Stillman Rubber Co.	Based on Ref. 5
Viton B (555)	1	1.0	0.6	99	No effect after 72 hr at 150°F, 7 days at 150°F, sl. blistering	DuPont	O-rings, seals, bladders
Viton B (555)	4	-	3.6	98	7 days at 150°F, sl. blistering	DuPont	Not recommended
Viton Butyl-A-5	1	0.7	-	98	None	Seals Eastern	Gaskets, seals
Viton Butyl-A-5	3	-	5.0	91	V. sl. blistering	Seals Eastern	--
Viton Butyl-A-5	1	2.5	-	32	None	Seals Eastern	Gaskets, seals, O-rings

(1) Acid = Active chlorine basis, wt. %
 See Procedure 2, Table 12.
 (2) Acid = 10% H₂O₂ at 20°C
 (3) Acid = 10% H₂O₂ at 150°F
 (4) Acid = 10% H₂O₂ at 150°F
 (5) Acid = 10% H₂O₂ at 150°F - 50 psi
 Eastern Seals experience

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TABLE IX

COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH POLYVINYLCHLORIDE AND CO-POLYMERS*

Material	Classification	Effect of Sample on H ₂ O ₂			Apparent Effect of H ₂ O ₂ on the Sample	Source of Material
		wt% ACO ⁽¹⁾ per Week at 65°C	Stability ⁽²⁾ After Test	—		
Almond tubing	3	10.3	--	—	Embrittled	Malco Company
Baltaron 600 (gray)	2	3	—	—	None	The Balta Co.
Gesa 115 ⁽³⁾	3	8.5 (4 days)	85.6 (4 days)	—	Milky white, blistered and distorted	B.F. Goodrich
Gesa 404 (yellow)	3	8.0	—	—	Bleached and become brittle	B. F. Goodrich
Gesa PVD Pipe Gray	2	1.1 ⁽⁶⁾	85	—	Slight bleaching	B. F. Goodrich
I.P.S. Uccalite	3	10.6	97	—	Slight bleaching	B. F. Goodrich
Koroseal 115 ⁽⁴⁾	3	7.2	89.8	—	Severely blistered and blistered	Stritt & Price
Koroseal 117 ⁽⁵⁾ (unfilled)	3	23	—	—	Bleached and hardened	B. F. Goodrich
Koroseal 700 ⁽⁶⁾	2	2.9	—	—	Bleached and hardened	B. F. Goodrich
Koroseal 700 with Hyper 1041 plasticizer	4	18.9	0	—	Blistered and bleached	Prince Rubber Co.
Lacoflex (translucent)	3	10.1	—	—	Blistered and bleached	Lacoflex Plastic Fabricating Co.
Lacoflex (white)	3	11.2	—	—	Bleached, slight blistering	Lacoflex Plastic Fabricating Co.
Marvinol 218-200	4	100/2 hr	—	—	Sticky before tacky after 1 hour	U. S. Rubber Co.
Marvinol 218-201	4	100/1 hr	—	—	Deformed, charred	U. S. Rubber Co.
Marvinol EP-300 ⁽⁷⁾	4	100/1 hr	—	—	Sample became tacky	U. S. Rubber Co.
Marvinol EP-6010	4	100/1 hr	—	—	Sample deformed, became tacky	U. S. Rubber Co.
Pilow ⁽⁸⁾	2	—	—	—	—	Goodyear Tire & Co.
Polyvinylchloride	2	1.2 - 10.9	87 - 98	—	Moderate bleaching	Malworth Pipe
Rigid	3	13.1	87.7	—	No change	Prince Rubber Co.
Sheet (dark gray)	2	9.3	90.4	—	Bleached and slight blistering	Vanco Co.
Seron Rubber G-187	2	12.3	—	—	Bleached	Whitehead
Transfer Tubing	4	—	—	—	Burned	Prince Rubber Co.
Type B-20	3	2.3	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-32	3	2.2	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-63	3	1.7	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-71	3	3.5	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-72	3	1.0	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-156	3	2.0	—	—	Bleached, blistered, and distorted slightly	Dow Chemical Co.
Type B-2041	4	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-2043	4	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-27	4	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-30	4	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-31 ⁽⁹⁾	4	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-32 ⁽⁹⁾	2 ⁽⁷⁾	—	—	—	Bleached, swollen	U. S. Stoneware
Type B-33 ⁽⁹⁾	2 ⁽⁷⁾	—	—	—	Bleached, swollen	U. S. Stoneware
Vinylite VU 1000 ⁽¹⁰⁾	2	1.7	—	—	Bleached, swollen	U. S. Stoneware
Vinylite VU 1007	3	3.0	—	—	Burned opaque, slight blisters	Elastolite Div.
Vinylite VU 1014 ⁽⁹⁾	2	1.9	—	—	Bleached, slight blisters	U. S. Rubber Co.
Vinylite VU 1016 ⁽⁹⁾	2	—	—	—	Burned opaque	U. S. Stoneware Co.
Vinylite VU 1016 ⁽¹¹⁾	3	2.3	—	—	Burned opaque, slight blisters	Elastolite Div.
Vinylite VU 1900	3	2.9	—	—	Burned opaque, slight blisters	Elastolite Div.
Vinylite VU 1900	3	2.0	—	—	Burned opaque, slight blisters	Elastolite Div.
Vinylite VU 1930	3	2.4	—	—	Burned opaque, slight blisters	Elastolite Div.
Vinylite VU 1940	2	1.6	—	—	Bleached	U. S. Rubber Co.
Vinylite VU 1940	3	2.0	—	—	Burned opaque, slight blisters	Elastolite Div.

* Except for 1 unless otherwise noted.

(1) Average weight loss, wt%

(2) For Class 1, 2, 3, 4, 5, 6, 7

(3) Ref. 2 cited Lycra 115 as being Class 4

(4) Ref. 2 cited Koroseal 115 as being Class 3

(5) Ref. 2 cited Koroseal 117 (unfilled) as being Class 4

(6) Ref. 2 cites Elastolite 700 (unfilled)

as being Class 4

based on service experience

as tested by C

based on Ref. 2

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TABLE X

COMPATIBILITY OF 90% HYDROGEN PEROXIDE WITH SILICONE RUBBERS*

Material	Classification	Effect of Sample on H ₂ O ₂		Apparent Effect of H ₂ O ₂ on the Sample	Source of Material
		wt% loss ⁽¹⁾ per week at 65°C	Stability after test ⁽²⁾		
Fluorosilicone LS-53	2	16.7	91.3	None	Dow Corning
GE 407B-217-1	4	34.3	--	Hardened	General Electric Co.
GE 1240	2	72.4	--	None	General Electric Co.
GE 61223	2	27.7	--	None	General Electric Co.
GE 12601	4	99.5	--	Hardened	General Electric Co.
GE 12602	3	95	--	None	General Electric Co.
GE 12650 (unpigmented)	2	48.5	--	Slight swelling	General Electric Co.
GE 12650 (pigmented red)	3	89	--	Slight bleaching, swelled, distorted	General Electric Co.
GE 12670	4	47.5	--	Hardened	General Electric Co.
GE 12670 (pigmented brown)	4	45	--	Cracked, bleached	General Electric Co.
GE 15060 (pigmented)	3	31.9	--	Blistered and warped slightly	General Electric Co.
GE 15030	3	32.2	--	Blistered	General Electric Co.
GE X-7131	3	18.3	--	Slightly hardened	General Electric Co.
Parkers White 467-1 "O" ring	4	29.6	--	Hardened and broke	Parker Appliance
SE 450 (unpigmented)	2	13.3	--	Very slight bleaching and swelling	General Electric Co.
Silastic 152	2	17.8	68.1	Slightly bleached	Dow Corning
Silastic 160	3	37.8	--	Lost elasticity	Dow Corning
Silastic 160 "O" ring	4	71	--	Embrittled	Linear Inc.
Silastic 161	3	43.4	--	Lost elasticity	Dow Corning
Silastic 181	3	39.3	--	Slightly blistered	Linear Inc.
Silastic 240	2	24.9	--	None	Dow Corning
Silastic 250	4	92.6	--	Curled	Dow Corning
Silastic 261	3	16.7	--	Lost elasticity	Dow Corning
Silastic 675	3	5.0	--	Blistered and embrittled	Dow Corning
Silastic 6-128	2	6.7	99.7	Bleached, very slightly blistered	Dow Corning
Silastic 7-130	3	17.7	--	Embrittled	Dow Corning
Silastic 9711	2	7.4	99.1	Slightly bleached	Dow Corning
Silastic SE-9711	2	7.8	95.5	Slightly bleached	Hewitt-Robins
Silastic SE-9561(3)	2	--	--	--	Hewitt-Robins, Inc.
Silastic 9711 welded with S-2200	2	13.6	96.0	Weld unaffected. Slight bleaching and mottling	Dow Corning
Silastic S-2000-4-480	2	16.1	95.5	Blistered and mottled slightly	Dow Corning
Silicone 407-B-217-1	3	39.5	--	Embrittled	P. S. Bacon Lab.
Silicone 407-B-437-1	2	20.3	--	None	P. S. Bacon Lab.
Silicone 511-015	3	17.4	95.7	Blistered	Conn. Hard Rubber Co.
Silicone X-1011(3)	3	--	--	None	Union Carbide Corp.
Silicone S-1-1011(3)	4	--	--	Lost flexibility, cracked	Union Carbide Corp.
Silicone 6-2711(4)	--	--	--	No noticeable attack, until bleached (166 hr at 200°F)	Fargo Rubber Co.
Silicone SR 7109	2	30.4	--	None	Conn. Hard Rubber Co.
Silicone SR 1-10	2	30.9	--	None	Conn. Hard Rubber Co.
Silicone SR 1-10	2	43.0	--	None	E. I. DuPont
Silicone SR 1-170	2	46.5	--	None	E. I. DuPont
Silicone X-7-11	3	18.3	--	Lost some elasticity	Stearart Rubber Co.
Silicone Y-11/9	2	12.3	--	Small white blisters	Carbide & Carbon Co.
Silicone SR-1001	2	15	96	Bleached slightly	Stillman Rubber Co.
Silicone SR-1007	2	10.3	97	No effect	Stillman Rubber Co.
Silicone SR-1007(4)	--	--	--	No apparent attack (1 day at 200°F) slightly attack after 166 hr at 200°F	Stillman Rubber Co.
Silicon SE-1017(4)	--	--	--	No apparent attack (166 hr at 200°F)	Stillman Rubber Co.
Silicone Rubber Comp. TS-033(5)	--	--	--	No noticeable attack (1 day at 200°F), slightly blisters after 166 hr at 200°F	Parker Seal Co.
Silicon Carbide(4)	3	--	--	None	Union Carbide Corp.

^a Unless otherwise otherwise noted

(1) Acetone oxygen loss, wt%

(2) See Footnote 2, Table II

(3) Based on Ref. 2

(4) Based on Ref. 5

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Table XI (cont.)

<u>Experimen-</u> <u>tal</u>	<u>Concen-</u> <u>tration</u>	<u>wt. loss (1) per</u> <u>week at 65°C</u>	<u>Stability (2)</u> <u>After Test (2)</u>	<u>Apparent Effect</u> <u>of HgO2</u> <u>on the Sample</u>	<u>Source of Material</u>
Epoxy Plastic	4	6	55	Disintegrated	B. F. Goodrich Co.
Coumarin (2,2')	4	100% in one hour	--	Sample fell apart	Carlock Packing Co.
Formaldehyde (10%)	4	100/24 hrs	--	Dissolved completely	P. S. Beeson Labs.
Formaldehyde (20%)	4	100	--	Partially disintegrated	Haverg Corp.
Formaldehyde (30%)	4	100	--	Dissolved	Haverg Corp.
Formaldehyde (clear)	4	100	--	Disintegrated, clumped	Houghton Labs.
Formaldehyde (color)	4	100	--	Disintegrated, clumped	Houghton Labs.
Formaldehyde	4	100	--	Disintegrated, clumped	Houghton Labs.
Formaldehyde	4	100	--	Disintegrated, clumped	Houghton Labs.
Formaldehyde	4	100	--	Disintegrated, clumped	Houghton Labs.
Formaldehyde	4	100	--	Disintegrated, clumped	Houghton Labs.

(1) See footnote 2, Table II

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TABLE XI (cont.)

Material	Concen. ppm	Wt. lost (1) per AASHTO Spec. (2)	Stability of HgO ₂ in the sample	Source of Material
Pencil b-703 (Senns)	4	100	--	Flattened, distorted.
Pencil b-703 (edges)	4	100	--	Flattened, distorted.
Pencil b-703 (edges)	4	100	--	Flattened, distorted.
Pencil C-703 (edges)	4	100	--	Flattened, distorted.
Pencil C-703 (edges)	4	100	--	Partially disintegrated
Pencil	3	26.7	--	Swollen and distorted
Pointed	2	2.1	97	Slight bloating
Pointed (1377)	4	100	--	Partially disintegrated
Point A	1	5.0	--	None Different
Point B	1	1.7	--	None Different
Postume Pure Gun	4	--	--	Imited and burned

(1) Weight loss, %
(2) AASHTO Spec. 2, Table XI

TABLE XI (cont.)

Material Reference ER 355-B	Concen- tration	Wt% AOL (1) at 65°C		Stability (2) After Test (2)	Apparent Effect of H_2O_2 on the Sample	Source of Material
		Wt% AOL (1) at 65°C	Wt% AOL (1) at 65°C			
PVC	4	--	--	--	Ignited and burned	--
COP (1)	4	--	--	--	Dissolved	DuPont
COP (1)	2	--	--	--	--	--
PVC-Catalyst	4	100	--	--	--	Hercules Chemical
Terephthalic	4	100	--	--	Sample burned	Durez
Terephthalic	4	100	--	--	Softened and partial solution	Rohm & Haas
Terephthalic (1,4)	2	9.1	--	--	None	Flex Corp.
Terephthalic (1,4)	3	0.5	50.2	Partially dissolved	Dunlop	
Terephthalic (1,4)	3	56.0	59.9	Completely dissolved	B. F. Goodrich	
Terephthalic (1,4)	4	93.5	0	Completely dissolved	B. F. Goodrich	

(1) % oxygen loss, wt
(1) Ref. 2, Table II
(1) Based on Ref. 2

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TABLE XI (Concluded)

Material	Classifi- cation	wt% AOL (1) Weight at 66°C		Stability (2) After Test (2)	Apparent Effect of N_2O_2 on the Sample		Source of Material
		wt%	Time		on the Sample	Source of Material	
Thickol EC-601-LP2	4	100	0	0	Burst into flame		Thickol Corp.
Thickol 3000 FA	4	100	--	--	Dissolved		Thickol Corp.
Thickol 3000 ST	4	--	--	--	--		Thickol Corp.
Thickol 1000 AH	4	--	--	--	--		Thickol Corp.

(1) Active oxygen loss, wt%
(2) See Footnote 2, Table II

TABLE XII

COMPARISON OF 90% EXPOSED PERIODS WITH INTEGRATES, MATERIALS AND ALTERNATIVES (REV. 1)

Material	Classification	Effect of sample on H_2O_2		Apparent Effect of H_2O_2 on the sample	Source of Material
		wt% AOL (1) at 65°C	Stability (%) After Test (2)		
Ceramic MT-411 (ceramic fibers/glass)	2 (3)	11.5	70.1	Blaesched during screening	U.S. Gasket
Epoxy 500 (fiber- reinforced version)	3	44.7	None	Rogers Corp.	
Fiberglass FG77-157 (Vitron A, 115 glass)	3	29	91.6	Moderate blistering and surface attack	DuPont
Fiberglass FG77-158 (Vitron A, Ecoron)	2	23	94.5	Moderate surface attack	DuPont
Fiberglass (Viton A)	2	48.4	None	DuPont	
515	2	53.9	None	DuPont	
517	2	7.5	None	DuPont	
520 (1/32 in.)	2	4.0	None	DuPont	
Glass Fassine	1	1.3	97.5	None	Over-Illinois Tech. Center
Fal-F-Macron Polymer-VL Liquid	4	95	Coating and Dacron separated in 2 days	Vernay Labs. Inc.	
Fal-F 5160 Macrone	2	30.6	Slightly blistered and tacky	Nichols Eng. Co.	
Fal-F 5200 (grey) Liquid	2	13.7	Slightly blistered and tacky	Nichols Eng. Co.	
Fal-F 5300 (grey) on Ecoron discharge	2	43.0	None	Nichols Eng. Co.	
Form Flex (Teflon coated glass fabric)	2	2.5	97	None	Chicago Gasket Co.

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TABLE III (Concluded)

Material	Classi- fication	Effect of Sample on H_2O_2		Apparent Effect of H_2O_2 on the Sample	Source of Material
		wt% AOL (1) Duct at 66°C	wt% AOL (1) per Stability (2)		
<u>Polyester Fiberglass</u>					
Dunbar 1000	3	25.9	15.7	Bleached	Will Corp.
Cord-5	3	10.6	61.7	Bleached	Will Corp.
Cord-4	3	21.4	70.0	Bleached	Will Corp.
Cord-8	3	49.5	39.8	Bleached	Will Corp.
E	3	15.0	10.7	Dissolved & Discolored & bleached	Will Corp.
Fab	3	12.0	79.7	Discolored & bleached	Buffalo Forge Co.
Fraw	3	22.0	28.0	Discolored & bleached	Buffalo Forge Co.
Mation	3	27.4	67	sl. dissolved & bleached	East Process & Equip. Co.
Gillette 72-771 on Duoron duxtrage	3	9.7	96.4	Blistered and distorted	Kirkhill Rubber Co.
Vinyl coated Fiber- Glass (Grey-Green)	3	49.8	---	None	Burns Mfg. Co.
771 silicone coated fiber PC A 450, adhesive (Poly-Cotton 3 Laminated base) C3 aluminum	3	15.5	69.1	None	Kirkhill Rubber Co.
771 silicone coated fiber PC Cordage COT adhesive on aluminum	3	11.6	83.4	None	Kirkhill Rubber Co.

- (1) Active oxygen loss, wt%
 (2) See footnote 2, Table II
 (3) After 2 hr screening at 66°C

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TABLE XIII
COMPATIBILITY OF 98% HYDROGEN PEROXIDE WITH VARIOUS PLASTICS (Ref. 1)

Material	Classifi- cation	Effect of Sample on H ₂ O ₂			Effect of H ₂ O ₂ on Sample	Source of Material	Comments
		Ht. & Act. (1) After Test(2)	No. @ 30°C After Test(2)	Stability @ 55°C After Test(2)			
Aclar	1	0.5	0.5	99	None	Allied Chemical Corp.	Tank liners, bladders
Fluorof 2340	1	0.9(3)	-	98	None	Minn. Mining & Mfg.	O-rings, seals, bladders
	4	-	-	98	Blisters after 24 hours at 151°F	Minn. Mining & Mfg.	"
Kal-f (4)	1	-	1.3	-	None	Minn. Mining & Mfg.	"
Kal-f D-316	2	-	5.1	97	V. sl. bleaching	Seals	Bladder material
Kal-f D-395	2	-	6.3	94	V. sl. bleaching	Rubber	Bladder material
Kel-f 800(3)	1	-	.33	98	None	Firestone	Seals
Polyethylene (4)	2	-	2.3	95	None	DuPont	Laboratory use
Polypropeno K-51	2	-	6.3	98	sl. bleaching	Polymer Corp.	Plastic parts
Teflon (Tefzel)	2	-	2.6	95	None	DuPont	Seals, gaskets
Teflon (fuel cell)	1	-	2.2(5)	97	None	Dielectric Corp.	Bladder material
Dispersion Teflon (fuel cell)	2	-	7.4(6)	94	V. sl. bleached	Dielectric Corp.	Bladder material
Dispersion Teflon	1	-	.33(6)	98	None	DuPont	Tank liner, bladders
VIT							
Vicose 3L-2	3	13	12.0	98	sl. bleaching	North American	Bladders
Vicose 1B5	2	1.3	2.4	99	v. sl. bleaching	North American	O-rings, seals, bladders
Viton A 271-7					Ex. service exp.	Parker Hannifin Corp.	O-rings, seals, bladders
Viton B 805	1	-	0.6	98.5	No effect to 72 hrs.	DuPont	O-rings, seals, bladders
Viton B 805	4	-	3.0	98	After 72 hrs. at 151°F	DuPont	O-rings, seals, bladders

NOTES:

- (1) Active oxygen loss, weight percent
- (2) See footnote 2, Table II
- (3) 5 months storage at 68-72°F
- (4) Subject to ignition if heated above 160°F when contact w/ 90% or 90% H₂O₂
- (5) 1 week at 120°F
- (6) 3 days at 165°F

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Polyethylene serves as an example of this phenomenon. Laboratory compatibility tests results indicated polyethylene to be suitable for Class 1 service. However, it was found that melting polyethylene in contact with 90 to 98% H₂O₂ ignites rapidly. Therefore, polyethylene is not recommended for service with 70 to 98% H₂O₂ unless no other material will meet the requirements; however, water immersion must be maintained throughout use. Clean polyethylene has been used safely in laboratory work, and polyethylene has proven to be a satisfactory material for use with 27.5 through 50% H₂O₂. Polyvinyl chloride and Dacron have both indicated they might react similarly to polyethylene with concentrated H₂O₂, and other lower-melting plastic materials may also react in this manner. Use of continuous water contact for cooling and for the dilution of spillage can prevent heat formation and a subsequent explosive reaction.

Materials for higher-temperature service, such as Kel-F and Teflon, have not demonstrated any indication of reaction with hydrogen peroxide over the entire concentration range and to temperatures up to 270°F with 90% H₂O₂. There is no known reason to avoid using the materials in any H₂O₂ service where the H₂O₂ will remain below its normal atmospheric boiling point. Mixtures of these materials with other materials must always be evaluated because reactions are varied. Glass-filled Teflon is acceptable; carbon filling may or may not be; asbestos filling is not. The compatibility of the added ingredient must, naturally, be considered. Kel-F, Aclar, and virgin Teflon are the most compatible plastic materials at high operating temperatures and should be utilized wherever the physical properties are suitable. It is especially recommended that these materials, which have exceptionally low coefficients of friction, be applied in H₂O₂ service as dynamic bearings and seals without lubricants wherever possible because of the limitations of the available lubricants. Two-hour tests at 270°F and 1000 psig with 90% H₂O₂ show that Teflon and Kel-F are not affected adversely. The active-oxygen loss (ACL) for the 2-hr period is similar to that experienced in tests at 151°F for seven days. Filled plastics such as Kel-F compounds, 9711 silicon, and Vitons show swelling at the high test temperatures.

Kel-F elastomeric compounds are generally inferior to Kel-F itself in compatibility with H₂O₂. In addition, compounded materials vary and, therefore, each finished compound must be specifically evaluated before compatibility can be assured. Most of the compounds tested have met the Class 2 criteria.

Aclar, Mylar, and Dacron plastics have demonstrated excellent compatibility with H₂O₂ in the laboratory, and Dacron has been used fairly extensively as cloth for protective clothing and reinforcement of other plastics which usually contact the H₂O₂. Mylar film has been applied very little because it does not heat-seal, and a compatible adhesive has not been found. Aclar is heat-sealable and is being used in the rocket field.

There are many plastic materials that break down upon extended exposure (1 to 7 days) to 90 and 98% H₂O₂ at elevated temperatures (150 to 165°F), but show no such effect in 24-hr exposure. Most Viton-A and -B and Fluorcel-2140

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and -2141 compounds show this effect. However, most service applications are at normal temperature conditions (50 to 120°F), and these plastics and rubbers show excellent service at such temperatures.

Specific Viton-A and Fluorel materials show Class 1 service at temperatures from 50 to 120°F. Viton-A 271-7 produced by Parker Hannifin Corporation has shown excellent service as O-rings in 90 and 93% H₂O₂ solenoid valves and for component seals. Seals Eastern Corporation's Fluorel 2140 and 2141 O-rings, seals, and bladders have proven rewarding in the moderate temperature range. David Clark Company's Omni (Viton-A) has proven satisfactory in O-rings, and in splash curtains when used to impregnate glass or Teflon cloth.

Polyvinyl-chloride-based materials vary in their reaction with H₂O₂ because of the plasticizer content and because other additives such as fillers and pigments are used. It is generally found that such additives reduce the compatibility of the compound with H₂O₂. Koroseal 700 (molded) has been extensively used as a gasketing material in low-pressure service. The formula for this material was developed specifically for H₂O₂ service in a cooperative test program with the manufacturer. Koroseal 116 and 117 (molded) are both inferior to Koroseal 700 for H₂O₂ service. Calendared Koroseal 117 is unsuitable because the H₂O₂ penetrates into the sheet and develops gas pockets which separate the layers of material. Calendared materials can only be made of materials which are absolutely impermeable to H₂O₂.

Polyvinyl chloride plastics are generally permeated by 90% H₂O₂. This has been found to be true for both molded and plastisol types of PVC. The absorption of H₂O₂ is indicated by the fact that the materials, which are generally clear or translucent, turn an opaque white after a period of contact with the H₂O₂. PVC containing absorbed H₂O₂ may be shock-sensitive (Appendix V). Hydrogen peroxide will also leach chloride ion from polyvinyl chloride plastics, which can cause corrosion of aluminum even when present in minute quantities.

Silicons-rubber elastomers also vary considerably in compatibility with hydrogen peroxide because of the use of pigments and fillers in some compounds. However, there are a number of these compounds, mostly unpigmented, which indicate Class 2 compatibility with H₂O₂. Of these, S-9711 has demonstrated the most satisfactory compatibility with 90% H₂O₂. S-9711 is used in various applications as an O-ring, gasket, hose, and bladder material. Although silicone rubbers are not subject to heat sealing, welding techniques have been developed, and S-9711 welded with S-2200 has indicated satisfactory compatibility with H₂O₂.

Silicone rubbers that indicate Class 2 results for H₂O₂ service are considered to be superior to polyvinyl chloride materials because the possibility of chloride leaching is eliminated and because the flexibility of the silicone varies much less with temperature over a wide range. Permeability of silicone rubber to H₂O₂ allows slow escape and causes layer separation due to oxygen evolution while in the pores.

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Some effective gaskets for joints of silicones 607 and 2-1000 to aluminum 6061 have been evaluated by the firm of Standard Gasket Co. Silicone 607 appeared to be most compatible, with Sil 2-1000 only slightly less so to it. With the effective present, compatibility should also prevail. It would be expected for the silicone rubber and aluminum alone; however, a control was not run for comparison.

Most of the materials discussed can be used as gaskets in the proper type of flanges. There are two reinforced SBR-like gasketing materials which have given satisfactory compatibility results and should find application. Kordex-flon, a Teflon-coated glass fabric, has indicated Class 1 results and Duratex 5010 yielded Class 2 results. The experience with either of these materials has not yet been gained.

A few tests have been made of Teflon-coated fabrics, usually a plastic-and-cloth sandwich type construction, using 607 as gasket fabric. The compatibility of these diaphragms with H_2O_2 has been excellent, except when using Cami (Viton-4) impregnated glass, Teflon, or PTFE cloth. Polyethylene sheet and pure Viton diaphragms have been utilized successfully in pressure transducers with water on the pressure-gage side, and pure Viton diaphragms have been utilized successfully in packingless valves such as the Crane EP-1600 series valves. Stainless-steel diaphragms have also been utilized satisfactorily.

5. Lubricants

The results of compatibility tests of 90% hydrogen peroxide with various lubricants and greases are summarized in Table IV. These results indicate that only the fluorinated hydrocarbons are sufficiently compatible with H_2O_2 to be considered for use. Even these materials can just very be caused to react with concentrated H_2O_2 if there is sufficient time applied to the mixture. However, use of fluorinated hydrocarbons has been satisfactory in transfer-pump packing glands with 90%-series stainless-steel shafts.

As they are now constituted, fluorinated hydrocarbons do not possess good lubricating qualities, and the viscosity is very low at room temperature. Some lubricants which are oil-base greases are really satisfactory, principally because of the difficulty of attaining stable emulsions.

In addition, the use of silicone-based lubricants as lubricants for aluminum may lead to deterioration and/or embrittlement. The influences of such substances have been investigated during a laboratory experiment on aluminum pipe using Fluorolube as a coating. First, the outer vinyl fluorinated hydrocarbon was used as a thermal insulation on the outside heat shield of a hydrogen-peroxide decompositon chamber. It is reported the material is the laboratory by decomposing aluminum hydride as an liquid shield in powder form.

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TABLE IV

COMBUSTIBILITY OF 90% FLUOROCARBON POLYMERS WITH LIQUID OXYGEN (REF. 1)

Material	Classifi-	Effect of 100%		Impact	Source of Material
		Oxygen in liquid nitrogen	Impact of liquid nitrogen		
Alkuterg C	4	--	--	Yes	Chem. Solvents
Amino Silane Oil and Grease	4	--	--	Yes	--
Apiezon Kuriwax N	4	Excess.	--	Yes	J. G. Riddle
Arochlor 1221	4	--	--	Yes	Monsanto Chem. Co.
Arochlor 1232	4	--	--	Yes	Monsanto Chem. Co.
Arochlor 1242	4	--	--	Yes	Monsanto Chem. Co.
Arochlor 1248	4	--	--	Yes	Monsanto Chem. Co.
Arochlor 1254	4	--	--	Yes	Monsanto Chem. Co.
Bardahl	4	--	--	Yes	Bardahl Corp.
Carrv 200	4	5.2	--	Yes	Koco Labs.
Ceresin Max	4	--	--	Yes	--
CFZ-1	4	--	--	Yes	Carbide & Carbon
Dichloro-bis-tri-fluoromethyl benzene	3	3.3	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Dichlorobenzofluorobutene	3	9.2	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube FS	2	4.2	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube FS plus 5% Fluorolube light grease	2	--	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube heavy grease 10214	2	1.7	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube oil 10213	2	1.0	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube S	2	2.5	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube T	2	8.5	No ⁽²⁾	Yes	Koehler Electro-Chem. Co.
Fluorolube Oil, S-30	2	--	No	Yes	Koehler Electro-Chem. Co.
Fluorolube Grease, Mg-1200	2	--	No	Yes	Koehler Electro-Chem. Co.
Fluorolube Grease, GR-600	2	--	No	Yes	Koehler Electro-Chem. Co.
Formulation					
CS-16	4	--	--	Yes	Monsanto Chem. Co.
CS-2	4	--	--	Yes	Monsanto Chem. Co.
CS-23	4	--	--	Yes	Monsanto Chem. Co.
CS-37	4	--	--	Yes	Monsanto Chem. Co.
CS-48	4	--	--	Yes	Monsanto Chem. Co.
CS-50	4	--	--	Yes	Monsanto Chem. Co.
CS-52	4	--	--	Yes	Monsanto Chem. Co.
CS-53	4	--	--	Yes	Monsanto Chem. Co.
CS-54	4	--	--	Yes	Monsanto Chem. Co.
CS-55	4	--	--	Yes	Monsanto Chem. Co.
CS-57	4	--	--	Yes	Monsanto Chem. Co.
CS-58(1)-2	4	--	--	Yes	Monsanto Chem. Co.
Epiro. (uncolored)	4	1.0	--	Yes	Monsanto Chem. Co.
E-2 Hydraulic Fluid	2(3)	--	--	Yes	R. M. Hollingshead Corp.
Elastocarbon Oil S-25 AV	2	1.0	No ⁽²⁾	Yes	Elastocarbon Products
Elastocarbon Grease, Series E-10	2(3)	--	No	Yes	Elastocarbon Products
Elastocarbon E-10-25 Stepwick Grease	2(3)	--	No	Yes	Elastocarbon Products
Elastocarbon Oil 10-21(4)	2	2.9	No ⁽²⁾	Yes	Elastocarbon Products

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TABLE IV (cont'd.)

Material	Molecular Weight	Effect of Dilution on the Tg's		Supplier
		at 10% by weight	at 50% by weight	
Malcoart Oil 11-11 ⁽⁴⁾	2	2.1	5 ⁽²⁾	Malcoart Products
Malcoart Shop Cook Grease	2	1.8	No	Malcoart Products
Monochlorobutadiene	3	3.7	No ⁽²⁾	Eckar Electro-Chem. Co.
Monochloropropylene	4	100	--	Eckar Electro-Chem. Co.
Hydraulic Fluid EHM	4	1.4	Yes	Standard Oil of California
Hydraulic Oil Knudsen Safe 600	3	7.1	--	Knudsen Co.
Kel-P Alkane	2	1.0	No	Minn. Mining & Mfg. Co.
Kel-P Oil Cut No. 1	2	1.7	No ⁽²⁾	Minn. Mining & Mfg. Co.
Kel-P Oil No. 10	2	3.2	No ⁽²⁾	Minn. Mining & Mfg. Co.
Kel-P No. 90 Grease	2	33.2	No	Minn. Mining & Mfg. Co.
Lindol EP (tricresyl phosphate)	4	--	Yes	Calsilco Corp.
Lindol EPX	4	--	Yes	Calsilco Corp.
Liqui-Moly concentrate	4	--	Yes	Gilmore Molybdenum
Lubri Seal	4	--	Yes	Arthur E. Thomas Co.
Mineral Oil	4	--	Yes	Various suppliers
Paraffin	4	--	Yes	Various sources
Perfluorolube grease FC-759	2	10.5	No ⁽²⁾	DuPont
Perfluorolube Oil FC-331	2	1.4	No ⁽²⁾	DuPont
FC-332	2	1.7	No ⁽²⁾	DuPont
FC-333	2	1.4	No ⁽²⁾	DuPont
FC-334	2	0.8	No ⁽²⁾	DuPont
FC-335	2	1.0	No ⁽²⁾	DuPont
Petroletum	4	--	Yes	Various sources
Polychloropentane (stabilized)	4	--	Yes	Eckar Electro-Chem. Co.
Rexen	4	--	Yes	Atlan Power Co.
Silicone HV 22%	4	--	Yes	Dow Corning
Silicone Oil 50-7	4	--	Yes	Dow Corning
50-14	4	--	Yes	Dow Corning
50-19	4	--	Yes	Dow Corning
50-20	4	--	Yes	Dow Corning
50-21	4	--	Yes	Dow Corning
50-22	4	--	Yes	Dow Corning
50-23	4	--	Yes	Dow Corning
Silicone Oil 70-100	4	--	Yes	Dow Corning
70-100	4	--	Yes	Dow Corning
Silicone Oil 70-100	4	--	Yes	Dow Corning
70-100	4	--	Yes	Dow Corning
Silicone Oil 70-100	4	--	Yes	Dow Corning
70-100	4	--	Yes	Dow Corning
Silicone Oil 70-100	4	--	Yes	Dow Corning
70-100	4	--	Yes	Dow Corning
Silicone Oil 70-100	4	--	Yes	Dow Corning
70-100	4	--	Yes	Dow Corning
Styrol	4	--	Yes	--
1,1,2,2-tetrachloroethyl oxide polymer	4	--	Yes	DuPont
Sodium Fluoride	4	--	Yes	Ciba, Calgon
Tetra Hydrofuran 94	4	8.8	--	Gardner & Carter Chem.
		(Ppt. formed)		

⁽¹⁾ Determined at room, and 100° F. temperature.
⁽²⁾ Determined at 100, and 500° F. temperatures.
⁽³⁾ Determined at 100, and 500° F. temperatures.

There also is some indication that the presence of a fluorinated hydrocarbon in intimate contact with an organic material and concentrated H₂O₂ will cause the latter mixture to exhibit increased flammability. This information has not been adequately evaluated; therefore, it appears that the use of fluorinated hydrocarbons in conjunction with organic materials in concentrated H₂O₂ service should be avoided unless the specific system has been adequately tested. The best practice is to eliminate the need for lubricants if at all possible.

In evaluating lubricants for H₂O₂ service, the results of the impact tests are of greatest significance. Unfortunately, there is no standard impact tester and the reproducibility of most testers is only fair. The modified Bureau of Mines Impact Tester used for the results reported in Table 14 is simple to use and has been proven to be generally reliable, but it is subject to variations in results with different operators and with the condition of the initial plunger or weight. Despite the practice of regular cleaning of the gun barrel of the tester on the known explosive mixture of ethyl alcohol and 50% H₂O₂ in equal volume proportions, poor reproducibility has been experienced. Because of this situation it is felt that any positive determination should be sufficient to place a material in Class 4 for H₂O₂ service unless the proportions of lubricant and H₂O₂ in the mixture can be controlled within a proven safe range. Thus, although a lubricant or grease may pass all tests with negative results and then give a positive result in a later check test, it shall be classed as unsuitable for H₂O₂ service.

Pump-packing lubrication is one problem that can be overcome by the use of mechanical seals which require no lubrication. Seals made of 300-series stainless steel with ceramic and glass-filled Teflon mating surfaces and coated with the H₂O₂ have been applied successfully to centrifugal transfer pumps for several years.

6. Ceramic and Refractory Materials

The results of compatibility tests with ceramic and refractory materials are summarized in Table 17. Testing of materials in this category has been limited because application is often limited by their fragile nature. Most of these materials have been evaluated for application as filters as support or as filter elements contained in a filter assembly housing. Ceramic Ceramic AB-2 has been utilized extensively in conjunction with G-10 ceramic fibers for mechanical seals on centrifugal pumps using H₂O₂ to a extent for the seal. AB-2 and AB-400 have been evaluated but primarily for support, but no experience has been obtained with them. Filter C has been used for general filtering of H₂O₂. For filtering concentrated H₂O₂, better materials are being sought. So far, porous porcelain and biological filters have shown satisfactory service with 50 and 50.1 H₂O₂.

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EXHIBIT IV

**RESISTIBILITY OF 603 IRON AND STAINLESS STEEL CULTURES,
REINFORCING AND PROTECTIVE MATERIALS***

Material	Class- ification #(3)	Effect of Immersion Time at 100°C.		Apparent Effect of 500 hrs. at 100°C.	Source of Material
		Weight loss per cent	Effect on corrosion rate		
Agate (natural)	3	100	--	None	--
Agate (polished)	3	100	--	None	Buffalo Meter Co.
Al-Cu-Al ₂ O ₃ (Aluminum)	2	17.5	--	None	American Iron Co.
Alumina (ceramic) ⁽⁴⁾	4	--	--	Destroyed	General Electric Co.
Alumina 12-X6	2	19.1	--	None	Kayser Co.
Boron Nitride	4	--	--	--	--
Carboloy 4B-A	4	100	0	None	General Electric Co.
Carboloy 95-A	4	120	0	Eroded	General Electric Co.
Carboloy 78	4	100	0	None	General Electric Co.
Carboloy 999	4	100	0	None	General Electric Co.
Ceramic AB-2	2	6.5	--	None	Coors Porcelain Co.
Ceramic Al-200	2	12.6	--	None	Coors Porcelain Co.
Charcoal	4	--	--	Eroded	--
Corundum (Silicon Carbide)	4	100	--	None	Becton Co.
Glass, Pyrex	1 ⁽⁵⁾	--	--	--	--
Soft	2 ⁽⁶⁾	--	--	--	--
Graphite No. 30	4	--	--	Destroyed at room temperature	Ico Co.
Graphite 99.9% Carbon Black	4	100	--	None	Pure Bond Co.
Graphite 99.9% Carbon Black	4	100	--	None	Pure Bond Co.
Graphite 99.9% Carbon Black	4	100	--	None	Pure Bond Co.
Graphite 99.9%	4	Destroyed	--	None	Pure Bond Co.
Graphite	4	100	0	None	EMI Tech Carbon Co.
LiCl/MgO Catalyst	2	1.2	0.5	None	Chemicalrite Co.
Platinum	2	13.6	--	None	Becton Co.
Platinum Ruthenium, Copper Alloy	2 ⁽⁷⁾	--	--	--	--
Ruthenium	1 ⁽⁸⁾	--	--	None	Corning Glass
Silicon Carbide (Silicon Carbide)	1	0.8	--	None	Mitco Co.

- (1) 100 hr. at 100°C., 1 atm.
- (2) 100 hr. at 100°C., 0.033 atm.
- (3) 100 hr. at 100°C., 0.001 atm.
- (4) Not available.
- (5) 100 hr. at 100°C., 1 atm.
- (6) 100 hr. at 100°C., 0.033 atm.
- (7) 100 hr. at 100°C., 0.001 atm.
- (8) 100 hr. at 100°C., 0.001 atm.

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The only ceramic coating materials evaluated yielded unsatisfactory compatibility results in laboratory tests despite the fact that they are aluminum-nitride coatings. The poor results may be due to the method of coating, to added agents, or to the roughness of the coating.

Glass laboratory ware is used extensively for compatibility and stability tests as well as for general laboratory handling. Pyrex glass pipe is used extensively in the manufacturing facility for H_2O_2 service. Glass linings have been evaluated to a limited extent; the more common glass used for lining contains cobalt and therefore shows poor compatibility with H_2O_2 . However, some glass formulas do show excellent compatibility with H_2O_2 , but there is no use experience available with these linings.

Synthetic sapphire has not been applied extensively despite its excellent compatibility with H_2O_2 . Rotameter floats are probably the only present application.

7. Porous Materials and Filters⁽¹⁾

The results of compatibility tests of various porous materials are summarized in Table XVI. These materials are generally of interest for use in the filtration of hydrogen peroxide and thus will collect any dirt which gets into the H_2O_2 . Whereas a minor amount of catalytic dirt might be tolerated in a large tank of H_2O_2 , collection of this dirt on a filter in a relatively small quantity of H_2O_2 can cause considerable decomposition. Therefore, care must be exercised to keep the use of filters to a minimum and to select filtering media that will not readily react with decomposing H_2O_2 . For concentrations of H_2O_2 above 50%, low-melting materials such as Dacron are not recommended for filter elements.

Porous porcelain bacteriological filters have shown good service in H_2O_2 power system refueling operations. Porous Teflon and Kel-F are believed to be suitable for use as filter media. The Teflon cloth samples as supplied were a dark brown. In the first test of these samples, the brown color became pure white and the H_2O_2 stability was adversely affected. In repeat tests, the H_2O_2 stability was much less affected and the material gave Class 2 service results.

When applying porous stainless steel, the elements formed by clustering powdered metal must be avoided. Longtime durability effort in the control of the composition of granules and the porosity of the finished composite, no means have been found to make these materials suitable for H_2O_2 service. Porous stainless steel wire from wire, either annealed or drawn, yields Class 2 and 3 results. When using these materials for filter elements, welding should be kept to a minimum. 316 stainless steel screen filters have been used successfully in various 50% H_2O_2 fueling operations involving flight vehicles.

Filtrene-C has been used extensively for filtering all concentrations of H_2O_2 and for filters on storage and supply-line vents, but it is fragile

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TABLE XIV
COMPATIBILITY OF 90% H_2O_2 WITH POROUS MATERIALS (REF. 1)

Material	Classification	Effect of Sample on H_2O_2	Apparent Effect of H_2O_2 on the Sample	Source of Material	
		Wt % Act ⁽¹⁾ per Week at 65°C	Stability After Test ⁽²⁾		
Al-Si-Mg, Porous Ceramic #593	3	100/3 days	---	None	Lava Corp. of America
Alumina Oxide, Porous-EA-96	2	19	---	None	Norton Abrasives Co.
Armalon--Teflon Felt (Impreg.)	3	70	---	Bleached	DuPont
Armalon--	3	26	---	Bleached	DuPont
Bacron Cloth Dac-2100	2	5	---	Resiliency decreased	Ent. Filter Media Corp.
Dac-2101	2	3	---	Resiliency decreased	Ent. Filter Media Corp.
Dac-2102	2	3	---	Resiliency decreased	Ent. Filter Media Corp.
Filtros C Stone (55 Micron)	2	Classification based on experience	---	None	Filtros Corp.
Glass Cloth G-206-C	2	18	---	None	Ent. Filter Media Corp.
Poroloy--3022S Wire	3	100	---	None	Bendix Filter Div.
Porous Eal-F (15 Micron Pore)	2	9.8	98.0	Loss Brittle	Pall Filtration Cos.
Porous Porcelain (1.8 Micron)	2	16	---	None	Selas Corp. of America
Porous Teflon (9 Micron Pore)	2	14.0	96.5	None	Pall Filtration Cos.
Rigimash J SS. Wire	4	100	---	Deep bronzing	Pall Filtration Co.
Sintered 300 Series SS. Powder Compact	4	100/2 hrs.	---	Bronzed and rusted	Calif. Inst. of Tech.
Sintered 302 SS. Powder Compact	4	100/2½ hrs.	---	Bronzed	Amplex Div.
Sintered 316 SS. Powder Compact	4	100/2½ hrs.	---	Bronzed heavily	Titeflex Inc.
Sintered 316 SS. Powder Compact	4	100/2½ hrs.	---	Bronzed	Pall Filtration Co.
Sintered 3008 SS. Powder Compact	4	100/2 hrs.	---	---	S-E-C Research Assoc.
Sintered 135 & 130 SS. Powder Compact	4	100/5 hrs.	---	---	Macrocular Poly. Inst.
Teflon Cloth (12 Grade)	3	80	79	Completely bleached	Pall Filtration Cos.
Teflon Cloth--Felt (45 Grade)	2	17	98	None	Pall Filtration Cos.
Teflon Cloth (40 Grade) Teflon Felt (Impregnated)	3	15.3	83.1	Completely bleached	Pall Filtration Cos.
Teflon Cloth T-300	3	100	From bleaching	Bleached white	Ent. Filter Media Corp.
Teflon Cloth T-300	2	83.2	---	None	Ent. Filter Media Corp.

{1} Active oxygen loss, weight percent.
{2} See footnote P, table II.

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and difficult to back-wash. Replacement of this material for bulk uses is being investigated. It is not recommended for general-system uses.

When using filters for H_2O_2 service, it is important to keep them clean and to examine them frequently. When dirt on a filter is allowed to dry, oxidation may occur which causes this dirt to interfere in catalytic action. Therefore, it is a good policy to back-wash H_2O_2 filters immediately after use with distilled or clean potable water. Also flush the filter with suitable water before use.

8. Protective Coating Materials⁽¹⁾

The results of protective coating materials evaluations are summarized in Table XVII.

Protective coatings are not recommended for H_2O_2 storage - tank service, but they may be of value for special-purpose tanks and to protect incompatible materials from H_2O_2 splashes. Therefore, protective coatings have been evaluated for service with 90% H_2O_2 . Of these, only Teflon, Mol-P, and hot-air-sprayed polyethylene have indicated suitability for more than splash contact at temperatures of 160°F for Teflon and Mol-P and to 120°F for polyethylene, however; there has been no experience with such coatings in actual service. Splash-resistant coatings such as aluminum-dispersion Plastic Metal 22 have been used to prevent corrosion of steel surfaces in hydrogen-peroxide storage and handling areas, and the application of such coatings or paints is recommended for surfaces of materials subject to corrosion. Prevention of rust in H_2O_2 handling and storage areas is a safety measure because the possibility of contaminating the H_2O_2 is reduced.

Manganese-coated (electroless nickel) mild steel has shown good compatibility with 90% H_2O_2 . Tinplating, followed by a 400°F heat to seal the pores, has proved to be an effective material coating for H_2O_2 service.

It is believed that protective coating may be used to advantage in H_2O_2 service for prevention of corrosion of aluminum surfaces and for special cases of high-pressure feed tanks to allow fabrication from metals which possess high strength-to-weight ratios but are not sufficiently compatible with the H_2O_2 to allow a practical holding time.

In general, platings, such as tin plate, strip off when exposed to 90% H_2O_2 unless special precautions are taken. Apparently, the H_2O_2 seeps through pinholes in the plate or under the edge and then decomposes them if it contacts the undersurface liberating oxygen. The gas then forms a blister which eventually breaks and allows more H_2O_2 to contact the undersurface.

9. Joint Sealing Compounds⁽¹⁾

The results of physical and chemical tests of joint sealing compounds with 90% hydrogen peroxide are summarized in Table XVIII.

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TABLE III

RESULTS OF EXAMINATION OF PROTECTIVE COATINGS FOR 90% H₂O₂ SERVICE (REF. 1)

<u>Material</u>	<u>Results</u>	<u>Remarks</u>
Recommended Coatings for Long Time Contact and Splash Resistance		
Teflon	Compatible with H ₂ O ₂ over long periods. In Al 1060, 5-gal container tests H ₂ O ₂ concentration loss was 35.5 to 54.5% from 90.4% in 52 weeks.	Dispersion coated thermoplastic.
Kel-F (M.W. Kellogg Co.)	Compatible with H ₂ O ₂ over long periods. In Al 1060, 5-gal container tests H ₂ O ₂ concentration loss was 0.7% in 39 weeks, and 22.9% in 79 weeks from 90.0%.	Dispersion coated thermoplastic.
Kel-F on 1060 Al (Metal Cladding, Inc.)	Wt% AOL ⁽¹⁾ /wk @ 65°C = 0.0 H ₂ O ₂ stability ⁽²⁾ after test = 95%. No effect on sample.	Class 1 compatibility. Spray coating only.
Kel-F on 5254 Al (Metal Cladding, Inc.)	Wt% AOL ⁽¹⁾ /wk @ 65°C = 4.6 H ₂ O ₂ stability ⁽²⁾ after test = 98%. No effect on sample.	Class 1 compatibility. Spray coating only.
Kel-F on 5652 Al (Metal Cladding, Inc.)	Wt% AOL ⁽¹⁾ /wk @ 65°C = 3.4 H ₂ O ₂ stability ⁽²⁾ after test = 92.2%. No effect on sample.	Class 1 compatibility except slightly low stability after test. Spray coating only.
Glass-lining (clear) Light-grey (Pfaudler Corp.)	Wt% AOL ⁽¹⁾ /wk @ 65°C = 2.4 No effect on material.	Class 1 compatibility.
Glass-lining (Cobalt) Cobalt colored glass (Pfaudler Corp.)	Wt% AOL ⁽¹⁾ /wk @ 65°C = 3.0 No effect on material.	Class 1 compatibility.
Enameled coated + tin plated metals (Keystone Ceramium Co.)	Wt% AOL ⁽¹⁾ /wk at 65°C = 9 No effect upon material.	
Omni impregnated glass cloth or Teflon cloth (David Clark Co.)	Wt% AOL ⁽¹⁾ /wk at 65°C = 2.9 Wt% AOL ⁽¹⁾ /mo at 30°C = 0.5 No effect upon materials.	

(1) Active oxygen loss, wt%

(2) See footnote 2, Table II.

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TABLE XVII (cont.)

<u>Material</u>	<u>Results</u>	<u>Remarks</u>
Recommended Coatings for Splash Resistance Service Only		
Tygon Paint 7286 TP-81-clear	Blistered in 24 hr.	No other effects noted. Applied as ordinary paint.
Tygon Paint 71253 TY-107B (U.S. Stoneware Co.)	Blistered in 24 hr.	Applied as ordinary paint.
Corrosite No. 521 Corrosite No. 551 Corrosite No. 581 (Corrosite Corp.)	Blistered in 24 hr.	Applied as ordinary paint.
Plastic Metal No. 22 (Nat. Engrg. Prod. Inc.) 15th & New York Ave., N.W., Washington, D.C.	One small blister in 48 hours. Three small blisters in 9 days. (Most favorable for splash resistance.)	Applied as ordinary paint.
Saran Rubber Q-1875 (Dow-Chemical Co.)	Softened and blistered in 1 week.	Specially applied by manufacturer.
Mv--Type No. 150 (The Gregg Co.)	Blistered in 48 hr.	
Amercoat No. 1262 (American Pipe & Const. Co.)	Blistered in 24 hr.	Applied as ordinary paint.
Heillex (Heil Process Equip. Co.)	One small blister in 24 hr.	Applied by fabricator.
P-5, Co-Polymer (Watson Standard Co.)	Blistered in 24 hr.	Applied as ordinary paint.
Koolec Gray No. 8583 (Chamberlain Engr. Corp.)	Blistered in 24 hr.	Applied as ordinary paint.
Steelcote Stainless Steel (Steelcote Mfg. Co.)	small blisters overnight.	Applied as ordinary paint.

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Table 3 (cont.)

<u>Material</u>	<u>Results</u>	<u>Remarks</u>
Coatings Not Recommended for 50% H ₂ O ₂ Service		
Geon Latex 31X (B.F. Goodrich Co.)	Blistered in 24 hr.	Difficulty encountered in application.
Flexcoat No. 1 Black (Eisem Chemicals Co., Buffalo)	Blistered in 16 hr.	Blisters encountered in vapor phase.
Lithgow LC-600 (Gray) (Lithgow Corp.)	Blistered in 24 hr.	Applied by manufacturer.
Amercoat Red (Amer. Pipe & Constr. Co.)	Blistered in 7 hr.	
Prufoat Med. Gray (Prufoat Labs.)	Blistered in 24 hr.	Applied by manufacturer.
Lithgow LC (600) (Brown) (Lithgow Corp.)	Small blisters 7 hr.	Applied by manufacturer.
Veloform P-10 CFP304 (Firestone Rubber Co.)	Blistered heavily in 16 hr.	Applied by fabricator.
Cordo S-255A (Cordo Chemical Corp.)	Coating blistered in 12 hr.	Applied by dipping.
Cordo Plastic Coating (E-1 Resin + H-26 Activator)	Excessive H ₂ O ₂ decomposition and blister formation.	Applied by laboratory per instructions.
Chromalloy	High rate of H ₂ O ₂ decomposition and chrome leaching.	Applied by manufacturer to low carbon steel samples.
Unichrome Drum Lining B-124-17 (United Chromium Inc.)	Heavy blisters in 20 hr at 30°C. Heavy blisters in 3 hr at 65°C.	Applied by manufacturer.

Table 20 (continued)

<u>Material</u>	<u>Forming</u>	<u>Finishing</u>
Ucilon, System B Coating (United Chromium Inc.)	Heavy blisters in 3-1/2 hr at 30°C. Fire in 50 min at 65°C.	Applied by manufacturer with red lead base prime coat.
EX63B Paint (American Paint Co.)	Sample blistered and paint peeled on immediate contact.	Applied by fabricator.
Sealer EC801 with accelerator (Minnesota Mining & Mfg. Co.)	1. Uncured samples burst into flames. 2. Cured samples burst into flames. 3. Accelerator samples burst into flames. 4. Sealer showed no effect at room temperature.	

TABLE XVIII
**RESULTS OF PHYSICAL AND CHEMICAL EVALUATION OF JOINT SEALING
 Cements with CO_2 or H_2O_2 (Ref. 1)**

Compound Reference	Description	Furnace Test	Anti-scor- ing Test	Impact (A)	Compatibility Test, $\frac{\mu \text{m}}{\text{hr}}$, Loss/24 hr		Suitability For H_2O_2 Service	Recommendation
					Water	Acetone		
Polymers	Polyethylene Elast.	Pass.	Pass.	Pass.	Non-reactive	—	—	Not suitable
B. I. Rubber	Neoprene Rubber	Failed at 500 psi	Pass.	Pass.	Non-reactive	1.1	0.6	0.6
Vinylite	Styrene Resin Dispersion Chem. Co.	Pass.	Pass.	Pass.	Non-reactive	—	—	Recommended for H_2O_2 service but excess H_2O_2 causes a reaction temp.
Styrene	Styrene	2100 psi	2000 psi	Pass.	Pass.	Non-sensitive	1.0	—
Styrene Epoxy Comp.	Styrene	Passed at 500 psi	Passed at 25 psi	Pass.	Pass.	Impact sensitive	0.3	1.6
Styrene Glycidyl Ester Tenn. Oil Prod. Co.	Styrene	Passed at 500 psi	Passed at 25 psi	Pass.	Pass.	Impact sensitive	0.3	0.6
Chloro- Sulphur Oil	Chloro- Sulphur Oil	Passed at 250 psi	Pass.	Pass.	Impact from 10 trials	1.9	1.8	1.0
Phenol-C-15 C-15 Epoxy Co.	Phenol-C-15 Epoxy Co.	Passed, 0 psi	Pass.	Pass.	Impact sensitive 1 of 6 trials	—	5.1	—
Synthetic Organic Compounds	Synthetic Organic Compounds	Passed	Pass.	Pass.	Impact sensitive 1 of 6 trials	—	—	High decom- position rate
Cyan (Epoxy)	Cyan	Passed	Passed	Pass.	Non-reactive	15.1	—	3.6
Cyan A. Finsen Co.	Cyan	Passed at 500 psi	Passed at 500 psi	Pass.	Positive	—	—	High decom- position rate
Gum (Urethane) Cyan A. Finsen Co.	Gum	Passed at 500 psi	Passed at 500 psi	Pass.	Positive	—	—	Excess H_2O_2 decomp.
						—	—	Excess H_2O_2 decomp.
						—	—	Excess H_2O_2 decomp.

(1) 1 hr. at temperature of room temperature.

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TABLE XVIII (cont.)

Compound	Description	Sensitivity	Impact Sensitivity (%)	Compatibility Static Tests, % H_2O_2 Loss/24 hr				Remarks	Suitability for H_2O_2 Service
				100° Heat	100° Assembly	100° Storage	100° Heat		
Crofton Heat Control Chemical Co.	Unknown	---	---	---	---	---	---	Not fully evaluated	Not recommended
Hydrofluorite	Unknown	Not tested	Not tested	---	---	---	---	Previous decom- position at R.e. in contact at R.e.	Not suitable
Permalite Alumina Ceramic Grain #3	Unknown	Not tested	Not tested	---	---	---	---	Decolored 50% H_2O_2 at 30°C, 50% H_2O_2 @ 60°C	Not suitable for H_2O_2 service
Pyrolytic Silicon Carbide Reaction Chm. Ox.	Pyrolytic Silicon Carbide Reaction Chm. Ox.	Patented at 100° pat. 1968	Sens. Sens. Sens.	Impact sensitive	0.6	0.7	0.9	0.4	Because bleached
Pyromelt Refining Co., Tucson, Ariz.	Unknown	Patented at 100° pat. 1968	Sens. Sens. Sens.	Impact sensitive	1.1	0.9	0.2	2.0	Material dis- integrated
Pyromelt Metal Sht. Engg. Prod.	{#2 alum. Filter screen base, 100% Al, 10% filter, 10% base}	Patented at 100° pat. 1968	Sens. Sens. Sens.	Impact sensitive when wet	1.1	0.8	0.9	0.9	No change with exposure to H_2O_2
Pyromelt Pipe Prod. Portland Portland Co.	Unknown	Sens. Sens. Sens.	Sens. Sens. Sens.	Sensitive 2 of 3 trials	20.4	---	2.6	---	Not suitable
Syntex Ketamine Chem. Co. P.O. Box 600 Eng. Co.	Unknown dry (P.D.C.) and salt	Sens. Sens.	Sens. Sens.	Impact sensitive	1.7	---	2.6	---	Not suitable
---	Perlon-filter dispersion	---	---	---	---	---	---	---	---

(1) 1 hr = Impact at room temperature.

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TABLE XXVII (cont.)

Compound	Preparation	Compatibility Studies, $\delta \text{H}_2\text{O}$, Loss/24 hr.						Availability for H_2O_2 service
		Feeling	Absorb. H ₂ O	Impact Sensitivity (1)	Impact Resist.	Impact Rate	Impact Shrinking	
Excellent service experience, Class I material								
Sig. metallic stainless steel base	---	---	---	Impact resistive	---	---	---	Impact sensitive so not tested further
Stainless	Phased at 1000 psi	Pass.	Pass.	Pass. Impact resistive	11.6	---	3.1	High decom- position rate
Stainless	100	Pass.	Pass.	Impact resistive	2.2	---	0.2	Impact scaling
Stainless steel base	---	10	Pass.	Impact	---	---	0.2	Impact scaling and anti-shake
Stainless	Not Tested	Not Tested	Not Tested	Impact	---	---	---	Impact decom- position at H_2O_2
Stainless	Not Tested	Not Tested	Not Tested	Impact	---	---	---	Vigorous decom- position of SO_2 H_2O_2 at 65° C

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Most commercial pipe joint-sealing compounds have been found to be unsuitable for high-strength hydrogen-peroxide service. In systems for concentrations of less than 52 wt. % H₂O₂ Aviation Grade Formula 3 and equivalent have been used satisfactorily.

There are two thread compounds that have shown good service in 52 through 90% H₂O₂ systems. These are T-Film, a Teflon water-dispersed paste for small pipe threads and Teflon tape for 0.250- through 4-in.-size pipe threads.

Even approved joint-sealing compounds must be applied to threads for an H₂O₂ flow system in such a manner that no compound will enter the system. The compound should be used sparingly, only on the male part and not on the first two threads. Thus, the excess will press out of the threads.

Pipe threads should be avoided in H₂O₂ systems if possible; flanges and 37° flare connectors are recommended.

10. Protective Clothing Materials (1)

The results of compatibility tests of protective clothing materials with 90% H₂O₂ are summarized in Tables XII and XIII. These tests were directed primarily toward finding materials that would not ignite if 50% H₂O₂ were spilled on clothing soiled with catalytic dirt. The chief hazard encountered when concentrated hydrogen peroxide is accidentally spilled on a worker is the possibility that the worker's clothing will ignite. Secondly, materials were evaluated for resistance to deterioration by the action of concentrated hydrogen peroxide. From the results of tests (Table XII), it was found that in both the clean and soiled condition virgin Dacron in all forms, Saran-braided and 55% Dacron - 45% wool cloth resisted ignition. Dynel and Saran static fiber resisted ignition in the clean condition and ignited only with difficulty when soiled. Dacron was unaffected by 90% H₂O₂; Dacron-wool and Dynel were only slightly deteriorated. It must be noted that some treated and dyed Dacrons in the soiled condition will ignite with 50% H₂O₂. Samples must be tested before use.

Based on these tests, sources were developed for washable and impermeable clothing. This clothing and necessary accessories are described in Appendix V.

It must be pointed out that even protective clothing must be kept clean and particularly free of ordinary greases and catalysts such as chlorine compounds. Clean-soiled samples of Dacron, Dynel, and 55% Dacron-45% wool fabrics have been found to ignite and burn vigorously when treated with 50% H₂O₂. When laundering or cleaning Dynel fabrics, special techniques must be employed because of Dynel's low softening and melting points. Dacron may be laundered with no special precautions. Thus, Dacron is preferred for this reason and because of its better resistance to the H₂O₂.

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EMERSON & COOPER *Emerson & Cooper* *Emerson & Cooper* *Emerson & Cooper*

Sample	Source	Active Oxygen Loss at 222, m/mk		Inflammability Drop Test		Effect of H ₂ O on Fibers
		20°C	60°C	Class	Result	
FLAMMABLE MAT'L.						
DUROTAC						
Monofilament	U.S. Rubber Co.	1.0	12.1	No Effect	No Effect	Apparently none
Heavy Ride	C.W. Fung Co.	0.5	13.0	"	"	"
Staple fabric	Enviro Fabrics Inc.	0.3	13.4	"	"	"
Saran						
Monofilament	Saran Yarns Co.	0.5	6.0	"	"	"
Dacron-Wool 55% - 45%	Burling Millburn Co.	0.7	7.1	No Effect	No Effect	Weakened
Dynel	Burlington Mills	---	---	"	Burned	Partially discolored at 60°C
Saran (staple)	Saran Yarns Co.	1.3	4.0	No Effect	Burned	Apparently none
Vinytex "H"	Milburn Co.	1.9	4.0	"	"	Partially discolored at 60°C
INFLAMMABLE MAT'L.						
Polyvinyl- chloride	Milburn Co.	0.2	3.6	Not Tested		Endures on prolonged contact at 60°C, discolored and aged on exposure to sunlight at 60°C.
Flexigrip zipper	Flexigrip, Inc.	1.0	4.8	Ext. Effect		
(Vinyl)						

(1) Some polymer samples were treated with catalyst TiCl_3 and $\text{Al}(\text{C}_2\text{H}_5)_3$ contact with $\text{Si}-\beta\text{-LiC}_2\text{C}_6\text{H}_5$.

Dyed & Untreated, 100% Kevlar

[REDACTED]

(COMPARISON OF CLOTHING MATERIALS AND COTTON (NO. 1))

<u>Sample</u>	<u>CLOTHES COTTON</u>	<u>COTTON KEVLAR</u>
SCARF		
Cotton - Dye 50% 50%	Moderate Flammability Moderate Decomposition	Burns readily when soiled Burns readily when soiled
Scarf - Fiberglass 50% 50%	Moderate Decomposition	Weakened considerably
Leather	-----	Burns readily
Aluminized Scarf	Moderate Flammability Moderate Flammability Moderate Flammability	Burns readily when soiled Burns readily when soiled Burns readily when soiled
Scarf 50%, Segmented fiber 50%	Moderate Flammability Moderate Decomposition	Flammable Weakened considerably, crumpled when touched
SCARF - Kevlar.		
Aluminized cotton Scarf	Moderate Decomposition	Burns readily when soiled

[REDACTED]

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APPENDIX

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2. Concentrated Polymer Emulsion - Properties, Visc., Strength, Stability,
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3. Advanced Propellants Program, Internal Monthly Progress Rep. 2,
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4. Correlation of Various Corrosion Tests with Service Experience,
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~~CONFIDENTIAL~~

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APPENDIX IV

STORAGE AND HANDLING OF EXPLOSIVE POWDERS (u)

~~CONFIDENTIAL~~

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CONTENTS

SHIPPING CONTAINERS AND HAULING EQUIPMENT

A. SHIPPING CONTAINERS AND HAULING EQUIPMENT

1. Drums

a. General

There are two types of drums used to ship concentrated hydrogen peroxide: single-compartment and double-compartment drums. These drums are made of high-purity aluminum and are fabricated in accordance with IEC Specification 440. In accordance with IEC regulations, shipments of concentrated hydrogen peroxide may be made in double-compartment drums in full-car-load or less-than-car load lots. Shipments of concentrated peroxide in single-compartment drums are limited to full-car-load lots. Similar regulations apply to truck shipments.

Each of these types of drums has a rated capacity of 30.0 gal. The approximate tare weight of a single compartment drum is 42 lb and that of a double compartment drum is 50 lb. The net filling weights of concentrated hydrogen peroxide are about 300 lb and correspond to about 27 gal of liquid in the drum. The volume will vary with temperature.

A label carrying important instructions is affixed to each drum. It is essential that these instructions be read and followed by personnel handling the drums.

The seal wires on the fill caps should not be broken until the contents of the drum are to be used.

b. Single-Compartment Drum

The cap on the single, top-mounted bung of this drum contains a special sealing device called a Duron Disc Cap. The Duron disc cap is made of a resilient material that is compatible with hydrogen peroxide. The disc cap can be easily bent around to change shape under low pressure, but provides a tight seal when the drum is upright. When the drum is upright, holding the hydrogen peroxide, if the drum is tilted sharply or rolled over on end, the disc cap may not be sufficiently tight to allow easy leakage of the liquid, thus creating a hazard. Therefore, full drums should always be kept in a vertical position, even when being moved.

c. Double-Compartment Drum

There are two bungs on the top of this container, one for filling and emptying (located in the center) and the other for venting. The fill bung has a tube extending through the top compartment into the lower

compartment. Its cap has standard right-hand threads. The vent bung opens into the top compartment directly above a Bunsen diaphragm assembly mounted in the inner head. The vent cap has left-hand threads and incorporates a porous ceramic filter medium that allows vapor to escape but prevents entrance of dust and dirt.

The purpose of the upper compartment is to confine any splashing or leakage of hydrogen peroxide that might occur through the Bunsen diaphragm if the drum were accidentally tipped or rolled on its side. However, for additional safety reasons, this drum also should be kept in the upright position and never rolled. The vent cap should not be removed nor its seal wires broken until the entire contents of the drum have been used.

d. Drum Storage and Handling

General recommendations for the storage of hydrogen peroxide are given in Section B, whereas specific recommendations pertaining to drums are cited in the following paragraphs. Drums containing concentrated hydrogen peroxide should preferably be stored inside a building protected from the hot sun, inclement weather, and dust. Storage conditions should be such that the drums can be kept below 230°F in the event of a nearby fire, and the storage area should be ventilated to prevent the enrichment of oxygen in the atmosphere. Drums should preferably be handled on pallets with lift trucks. They should not be stored on wooden pallets nor stacked on top of each other.

Ample storage area must be provided for inspection and easy accessibility to the drums. Access aisles adequate for maneuvering drum-handling equipment should be provided around the drums and between every four rows of drums if stored singly, or between every two rows of pallets if stored on pallets. Individual drums should be sufficiently accessible to permit temperature checking by hand feeling.

The drums should be checked several times a week for excessive decomposition of the hydrogen peroxide and for leakage, particularly if they have been opened for any reason. In the unlikely event of excessive decomposition occurring in a drum (detected by visible bubbling and/or rise in temperature) the contents of the drum should be quickly disposed of in a safe manner. At the discharge facility, the drum should be uncapped, tipped over, and emptied, with simultaneous dilution and flushing with large amounts of water. If the hydrogen peroxide has reached the boiling stage or is giving off steam through the vent cap, the area should be evacuated quickly because of the possibility of an imminent rupture.

If a drum should develop leakage through the wall for any reason, the remaining contents should be used immediately or disposed of as described in the preceding paragraph. No attempt should be made to keep the peroxide by transferring it to another container.

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Because of probable contamination, hydrogen peroxide drums must not be refilled, not even with freshly removed peroxide, and certainly with no other material. Several drum explosions have occurred when the user refilled a drum with unused hydrogen peroxide. If the peroxide removed from the drum cannot be used completely, the excess remaining material should be flushed to the sewer with copious quantities of water.

Drums should be sampled only with a suitable siphon that is clean and passive.

Personnel emptying drums should work in pairs and should wear goggles, impermeable gloves, aprons, and shoes. Cases have been reported where spillage of concentrated hydrogen peroxide on leather shoes has caused the shoes to catch fire.

To prevent the entry of foreign matter, the bung cap should always be screwed tightly on the bung except when the drum is being emptied.

Drums should not be emptied by using air or gas pressure, because the product may be contaminated or the drum overpressurized.

It is hazardous to leave hydrogen peroxide in any equipment that is not vented. All pipe lines and hoses should therefore be drained when transfers are completed.

e. Methods of Emptying Drums

Several means of transferring concentrated hydrogen peroxide from top-outlet drums are in common use: siphons, special drum valves, self-priming pumps, and an ejector system operated by steam, water, air or nitrogen.

(1) Siphon Transfer

This method of emptying drums is normally used where only small quantities or low flow rates are desired, as in laboratory work.

The plastic tube siphon (sampling thief) usually is used for transferring or sampling small quantities of liquid. It is compact and light, washable, inexpensive, and easily purged. The fact that the vacuum-pump portion of the device may contain alloys unsuitable for hydrogen peroxide is immaterial, since the peroxide contacts only the plastic tube and not the metal.

The siphon can be used for sampling even large containers, such as tanks, because liquid can be withdrawn even from a considerable height with sufficient length of tubing. Its use, though, is limited to a closed type of sampling container, such as a sample bottle. The container must be equipped with cap threads (all the threads are the most common size) and must be capable of withstanding a partial vacuum.

A typical siphon is a commercial product known as the "Model D Golden Thief Vacuum Pump" (W. & W. Manufacturing Company, P. O. Box 9311, Chicago 90, Illinois). The procurement of the proper Tygon tubing required for this siphon is important for high-strength hydrogen peroxide service, and it should be checked when received.

The operation of this sampling device is quite simple: degrease the plastic tube with a 1% detergent solution and rinse with distilled water to make the tube passive; if necessary, subsequently "condition" the tube in hydrogen peroxide by flushing or by immersion for up to 24 hr, followed by another rinse with distilled water; slip the tube carefully into the vacuum pump, screw the pump onto the sample bottle, and dip the other end of the tube into the liquid to be sampled, taking precautions to keep everything scrupulously clean. A few strokes of the hand pump then should withdraw the desired amount of liquid. In so doing, avoid filling the bottle completely (to prevent contact with the aluminum pump) either by stopping the pumping slightly ahead of time or by withdrawing the tube from the liquid to break the vacuum.

Other siphons suitable for withdrawing from drums and transferring to an open container or to a large container can be constructed readily from aluminum tubing, glassware, and a squeeze-bulb aspirator for priming the siphon. Such a siphon is obtainable from at least one of the producers of hydrogen peroxide.

(2) Special Drum Valves

A single-compartment drum of concentrated hydrogen peroxide can be emptied through a drum valve. However, the design of a double-compartment drum precludes the use of such a valve. Valves in a passivated condition can be obtained from at least one of the hydrogen peroxide producers. Single-compartment drums are emptied through such a valve as follows:

- (a) The valve and the vent tube should be clean and in a passive condition before attaching the valve to a drum.
- (b) Remove the filling cap from the drum.
- (c) Insert the valve into the drum fill bung so that the tube will be in the vapor space when the drum is horizontal. With the gasket in place, screw the valve union nut to the bung.
- (d) Have available a hose with running water to flush away the few drops of hydrogen peroxide that will drain from the valve vent line when the drum is tilted to the horizontal position.
- (e) Be sure the drum valve is closed before tilting the drum.

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(f) Tilt the drum to a horizontal position with a drum-tilting rack.

(g) Fill the container by opening the valve. Since parts of the valve may not be rated for Class 1 service, contact of the valve with the liquid should be limited, particularly when the drum contents are to be consumed within a day or so. Also, when no liquid is drained from the drum (e.g., at night), the drum should be returned to its vertical position to remove the valve from contact with the liquid.

(h) When empty, return the drum to the vertical position.

(i) Remove valve and replace drum filling cap immediately.

(j) Rinse off drum valve with clean water and place in a clean polyethylene bag for later use.

(3) Other Drum-Emptying Systems

Two other suitable methods of draining hydrogen peroxide from drums where faster emptying or delivery under pressure is desired include self-priming and ejector systems.

The ejector system is one of the best methods of emptying drums because all parts in contact with the liquid can be made from Class 1 materials. Also, the receiving container can be constructed for pressure service and used as a blow case if desired.

All equipment of both of these systems must be clean and passive before being placed in service.

f. Directions for Returning Empty Drums

Before returning empty drums, completely fill with clean, potable water and drain. Both compartments of a double-compartment drum should be so rinsed. Be sure that all bungs are tightly seated on the gaskets. Then remove or obliterate the white "CAUTION" portion of the label as required by the ICC. Declare the empties for shipment as "Empty Drums, Aluminum, 16 Gage or Thicker."

2. Tank Cars

General

Hydrogen peroxide is available in tank-car quantities of 4,000, 6,000, and 8,000 gal. Tank cars are constructed of special aluminum in accordance with ICC Specification 103-A-AL-W and have top connections only.

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The tank-car appurtenances include: (1) a combination filter, an air connection, and a continuous safety vent, (2) a 2- or 3-in.-dia dip pipe for unloading, (3) a 4-in.-dia rupture-disc assembly, and (4) an 18-in. manway.

b. Tank-Car Unloading

Before unloading hydrogen peroxide from tank cars, the cars must be level, the brakes locked, and approved caution signs must be placed on the tracks at both ends of the car.

Caution to operating personnel: Do not add water or other liquid to hydrogen peroxide tank cars.

Dome fittings should be inspected for leaks or other defects. In the event of tank car or fitting failure, the producer should be contacted immediately by telephone or wire.

The best method of unloading concentrated hydrogen peroxide from a tank car is by means of a self-priming centrifugal pump. Although pumping is the recommended method, pressurization with clean, dry nitrogen may also be used. However, the producer should be consulted if pressurization with nitrogen is contemplated.

The step-by-step procedures for pumping concentrated hydrogen peroxide from tank cars are as follows:

(1) A hose with running water should be readily available to wash down spillage.

(2) Ensure that only recommended, compatible materials are being used.

(3) Ensure that all equipment (hose, pipe, flanges, etc.) is scrupulously free of oil, dust, or dirt.

(4) Flush unloading hose with clean, potable water and then drain hose completely.

(5) Fill the suction pot of the self-priming pump with deionized water or water distilled with equipment containing no copper or iron.

(6) After any dirt has been wiped off with a clean cloth, unbolt the flange on the dip pipe and connect the unloading hose to the flange. Remove the blind flange on the aluminum unloading line and connect the other end of the hose to the line.

(7) Ensure that the valves to the receiving tank are open.

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(8) Start the pump. Note: If samples of hydrogen peroxide are desired, they may be taken at this time from the pump discharge. Samples should not be taken directly from the car with a thief or other device because inadvertent contamination could create a safety hazard.

(9) When the tank car is empty, stop the pump and disconnect the unloading line from the dip pipe. Immediately replace the flange to prevent dirt and dust from entering the tank car. Be sure the gasket is in proper position.

(10) Wash the outside of the tank car and the ground thoroughly wherever the unloading line might have dripped hydrogen peroxide. Note: If drippage occurs during unloading, the area affected should be flushed with water immediately and continuously.

(11) Rinse out the unloading hose and elbow with clean, potable water and then cover their ends with aluminum blind flanges and polyethylene bag dust protectors. Store the hose inside for protection from weather and dust.

(12) Drain all lines and the pump of hydrogen peroxide. Flush pump with clean, potable water. When pump is not in use, leave all valves on the pump-discharge line open for venting purposes.

(13) Cover the end of the suction line to the pump with an aluminum blind flange or a polyethylene bag to prevent dust and dirt from entering the equipment while not in use.

Tank Trucks

In certain areas, deliveries of concentrated hydrogen peroxide are made by tank truck. Quantities of up to about 4,000 gal per load depend upon state load-limit restrictions. Transportation of hydrogen peroxide by tank truck is regulated by the ICC.

Tank trucks have complete unloading facilities, including hose. In contrast to tank-car deliveries, the unloading operation is handled by the truck operators rather than by the customer's personnel. Safety precautions similar to those pertaining to tank-car unloading apply also.

P. STORAGE FACILITIES

1. General Recommendations

Storage facilities for concentrated hydrogen peroxide should be isolated from other storage areas containing most other chemicals (particularly organic chemicals) and combustible materials. Isolation may be accomplished by means of fire walls or other suitable ways. Storage tanks should not be located in crowded areas, and preferably should be surrounded by a fence.

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All facilities should be as fireproof as possible. Wooden construction should be avoided, and the surrounding areas and drainage ditches should be kept free from vegetation. Asphaltic concrete, oiled roads, or wooden railroad ties are undesirable where spillage of concentrated hydrogen peroxide may occur.

Facilities should be as free of dust and dirt as possible. If dusty conditions prevail, consideration should be given to locating the equipment inside of a building. Good housekeeping is essential in preventing contamination.

Materials of construction must be carefully selected and prepared for compatibility with hydrogen peroxide.

All containers must have vents for the escape of the decomposition vapors. These vents should contain a filter to prevent dust from entering the container. Large storage tanks should also have a blow-off type of man-hole cover.

Storage tanks and pumps must be installed on a concrete pad leading to a drain separate from other plant drains and sewers to prevent the possibility of hydrogen peroxide mixing with other chemicals or combustible materials. The hydrogen peroxide drain should lead to a body of water or separate catch basin.

Adequate water facilities also should be provided for washing down spills and drainage of peroxide in the storage area. This flushing system should be protected from freezing during cold weather.

A water-flooding system should be provided so that, if necessary, large quantities of water could be introduced at the bottom of the storage tank, diluting and overflowing the contents of the tank through the manhole. This is best accomplished by installing a permanent flooding line that is blinded from, but easily connected to, the water supply. Another method would be to have a large, clean hose available to drop through the manhole to the bottom of the tank.

It is usually recommended that an external water-spray system or sunshield be installed over the tank to keep the tank cool. For the same reason, the tank should be located so that there is free air circulation around it.

If a sample is desired from the storage tank, it should be obtained either from the pump line when the peroxide is transferred or from a permanently installed sample connection.

All pipe lines should be designed to facilitate complete drainage. If possible, each pipe line will have only one valve. However, where two valves are required in the same line, a relief valve should be installed between the two valves to prevent pressure build-up.

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Transfer pumps should be drained and flushed with clean, potable water if they are to be left idle for two days or more or if it is necessary that the pump be blocked-in.

At least one eye-wash fountain and one safety shower should be provided in the storage area.

Clean storage conditions are essential for equipment or materials used with hydrogen peroxide, such as hoses, gaskets, water, etc.

Operating personnel should be provided with safety equipment, and warning and instruction signs should be placed in the area.

A good maintenance program should be set up including periodic reinspection of all equipment. All tools should be degreased before being used on hydrogen peroxide equipment, and only stainless steel or plastic tools should be allowed to touch interior surfaces.

2. Bulk Storage

Concentrated hydrogen peroxide can be obtained in bulk quantities and unloaded into storage tanks. These tanks usually range in capacity from 5,000 to 25,000 gal. The peroxide can be transferred from storage, possibly through one or more intermediate tanks, to its end use as desired.

The equipment and materials used in this entire system must be carefully selected, designed, fabricated, and prepared for service. The following section contains general information on equipment. Appendix III gives detailed data on materials compatibility, Section D presents design and fabrication information on storage and handling equipment, and Section E gives information on preparation of equipment for service.

3. Equipment for Bulk Storage Installations

a. Storage Tanks

Several experienced fabricators of hydrogen peroxide tanks and equipment are available from which the customer may make a selection. The economic size of a storage tank is determined by the user's consumption of peroxide. A minimum of four week's supply is normally recommended. Selecting a tank of standard size from one of the fabricators would afford the tank purchaser some savings. These tanks are usually fabricated from Aluminum Alloy 1060, containing 99.6% aluminum. Other suitable alloys are 5254 and 5652 if greater strength is required.

Horizontal storage tanks are standard, but vertical tanks may be used if desired. The tank connections should be flanged and should include an inlet and outlet connection, a manway, and an adequate vent protected by a suitable dust filter. These connections preferably should be located

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above the level of the liquid in the tank. In addition, a level gage, a temperature indicator for the liquid, and an alarm are recommended. Mercury thermometers and liquid type manometer gages should not be used in direct contact with the liquid.

Storage tanks for concentrated hydrogen peroxide usually are emptied by pumping. Since the outlet connection for the liquid is located on top of the tank, a self-priming pump is required.

Tank manufacturers should be thoroughly experienced in the fabrication of aluminum and should also be familiar with the special requirements of concentrated hydrogen peroxide equipment since particular care must be exercised to prevent steel, dirt, or other foreign particles from becoming imbedded in the aluminum during fabrication.

Storage tanks may rest directly on concrete saddles or may be supported by steel saddles bolted to concrete foundations. In either case the contact surface of the aluminum with the concrete or steel should be protected by an asphalt-saturated felt pad or similar material.

b. Measuring and/or Hold Tank

A measuring and/or hold tank not only provides a means of obtaining the desired quantity of hydrogen peroxide for a given use, but, very importantly, also serves to separate downstream equipment from the storage tank. Liquid from downstream thus is prevented from entering and possibly contaminating the storage tank. These tanks may be fabricated from a Class 1 or Class 2 material. The tanks can be pressure vessels, fitted with a vent and a gage-glass assembly, and may be equipped with bottom connections if desired.

c. Piping System

Piping should be fabricated from a Class 1 or Class 2 material. Aluminum Alloy 1060 is the preferred material, and should be used when the peroxide is in long-time contact with the piping. Alloys 3003 and 6063 are more readily obtainable from local sources and are suitable in many instances. The piping should be of welded construction, with fittings and joints minimized. Bends are preferred to elbows. Joints should be stub ends with lap-joint flanges or flanges welded to the piping. The use of stainless steel, galvanized steel, or aluminum-clad bolting with galvanized-steel back flanges is recommended since rusting of carbon steel would afford a source of possible contamination of the piping when the flanges are opened. The use of Schedule 80 aluminum piping is recommended. Its heavy wall construction facilitates jointing, makes it easier to achieve sound welds, and provides additional mechanical strength. Stainless-steel pipe or tubing may be required for certain services, particularly if high pressure is involved.

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Where the point of pump discharge is lower than the level of the liquid in the storage vacuum breaker to prevent siphoning after the pump is stopped. Also, for transferring concentrated hydrogen peroxide, the pump should be installed in such a manner that hydrogen peroxide is prevented from flowing back to the storage tank after each pumping. This may require either the draining of the pump discharge or a hold tank large enough to contain all of the pump discharge.

It is recommended that the number of valves be kept to a minimum to avoid the possibility of trapping peroxide between two closed valves. Where this could occur, either a relief valve should be installed in the line or one of the block valves should be kept sealed or padlocked in the open position so that it cannot be inadvertently closed.

Screwed fittings should not be used unless absolutely necessary. If such fittings are unavoidable, it is recommended that the tapered pipe threads be sealed with Teflon thread tape. Ordinary pipe-thread compounds must never be used.

d. Stainless Steel Equipment

Many parts for concentrated hydrogen peroxide service are fabricated from the 300 series stainless steels. These can include pumps, valves, instruments, and even tanks and piping. Wrought or forged types of stainless steel are much preferred to the cast types and usually can pass Class 2 specifications. The free machining types of wrought alloys may or may not be satisfactory. Difficulties frequently are encountered with the cast types. Castings of low-carbon 316 ELC are preferable. If practicable, it also is preferable to specify a maximum copper content of 0.2% for these materials. The copper content is not specified by the ASTM or the AISI, but is normally less than 0.5%.

Careful visual inspection of castings is necessary. Visual inspection should be augmented by a test to further ensure soundness and to detect iron contamination. This test consists of immersing the part in aerated distilled water for 24 hr at room temperature. The casting would pass the test if no rust spots appeared. A modification of this test is to rinse the casting in distilled water and then to put it immediately in a polyethylene bag so that excess water and air are present. The bag should be closed tightly and left for 24 hr before inspecting for rust spots.

Stainless steel is much more difficult to passivate than aluminum, particularly for use with concentrated hydrogen peroxide. Generally, smooth, wrought surfaces can be prepared satisfactorily by degreasing and subsequent passivating with nitric acid. However, cast surfaces, or rough scale, will usually require a pickling operation in a solution of nitric and hydrofluoric acids, between the degreasing and the nitric-acid-passivation steps.

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e. Valves

Globe or Y-valves are satisfactory; gate, plug, and ball valves usually have to be drilled or scored to prevent entrapment. A metal-to-Teflon seal usually is more satisfactory than metal-to-metal seals. Recent developments in certain types of ball valves have permitted these valves to be recommended for normal service.

f. Pumps

Since both tank cars and storage tanks for concentrated hydrogen peroxide have inlet and outlet piping at the top of the tank, self-priming pumps are required for transfer. A 2-in. self-priming centrifugal pump is normally used in this service. When transferring under flooded suction conditions, e.g., from a measuring or feed tank, a standard type of centrifugal pump may be used. Where higher pressures or low capacities are desired, a special rotary pump may be used.

Shafts of all pumps should be stainless steel and not aluminum. All pumps should be equipped with drain valves. Temperature alarms are installed sometimes to warn of overheating.

g. Flexible Connections

A corrugated, seamless hose of 304 or 316 stainless steel, with open-pitch construction and welded flanged ends, is recommended for use with concentrated hydrogen peroxide. Flexible hose lines with Teflon or silicone S-9711, and fitted with flanged connections, also have been used. Viton-A lined hose also shows promise.

Another type of flexible connection that has been used in this service is aluminum piping with swing joints (Barco) of stainless steel and Teflon.

h. Gaskets

Depending upon various service conditions, gaskets may be of any of the following materials: Teflon, Kel-F, special silicone rubbers and polyvinyl plastics, pure tin, aluminum, or stainless steel. Included in these materials are particular types such as the Teflon envelope over asbestos, and the spirally wound stainless-steel and Teflon (Flexitallic) styles. Gaskets containing metal usually are used on high-pressure or vacuum systems.

Elastomeric materials for this service should be selected with care since plasticizers or fillers in the elastomers can seriously affect their compatibility and because the material might be impact-sensitive in concentrated hydrogen peroxide. Only Class 1 or Class 2 materials should be used.

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i. Packing and Mechanical Shaft Seals

Teflon or Vitrium is recommended for packing in valves or similar equipment. These packings, when lubricated with a fluorinated hydrocarbon, also may be used on pump shafts, if necessary, providing the shafts are not made of aluminum, and providing that the packing glands are maintained loose enough to avoid overheating, which could result in rupture.

Single mechanical seals of the stainless-steel external type, with glass-filled Teflon rotating on ceramic faces, are recommended for pump shaft seals. The mechanical seal should be cooled, preferably by piping a small amount of the pump discharge to the seal.

Automatic temperature alarms and cut-offs, actuated by pre-set temperatures, may be used on pumps to warn of overheating. Installations should be such as to prevent the possibility of peroxide contacting any hydrocarbon lubricant in pump bearings.

j. Lubricants

The use of lubricants in concentrated hydrogen peroxide service should be kept at a minimum, and avoided completely if possible.

Only the fluorinated hydrocarbons, which are available in both oils and greases, are sufficiently compatible to be used with hydrogen peroxide. However, even these are not entirely satisfactory since they do not have good lubricating properties and are corrosive to aluminum. Moreover, detonating reactions have occurred without any hydrogen peroxide being present where heat developed when these materials were in contact with aluminum. Therefore, pumps sealed with packing and using one of these lubricants should be equipped with stainless-steel shafts and not with aluminum shafts.

Fluorinated hydrocarbon lubricants could also react with concentrated hydrogen peroxide, particularly in the presence of organic materials, if enough heat or force were applied to the mixtures. Tests to date are inconclusive in this respect.

4. List of Equipment Suppliers

Equipment which has been discussed in the foregoing sections may be obtained from the suppliers listed below. Although equipment furnished by these suppliers has in general been found satisfactory, the list is by no means all-inclusive, and no inference is intended that similar competitive equipment or material is unsatisfactory.

a. General Fabricators and Suppliers

Avins Fabricating Co., Inc.
Tonawanda, New York

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R. D. Cole Manufacturing Co.
Newnan, Georgia

Schwabel Fabricating Co., Inc.
North Tonawanda, New York

b. Pipe and Fittings

Adam Metal Supply
New York, New York and Elizabeth, New Jersey

Ducommun Metals and Supply Co.
Berkeley, Los Angeles and San Diego, California;
Phoenix, Arizona

Edgecomb Steel Co.
Milford, Connecticut; Nashua, New Hampshire; Charlotte,
North Carolina; Philadelphia and York, Pennsylvania;
Slaterstown, Rhode Island

Metal Goods Corp.
Denver, Colorado; Wichita, Kansas; New Orleans,
Louisiana; St. Louis and North Kansas City, Missouri;
Tulsa, Oklahoma; Memphis, Tennessee; Dallas and Houston,
Texas

Pacific Metals Co.
San Francisco, California; Boise, Idaho; Portland,
Oregon; Salt Lake City, Utah; Seattle, Washington

Steel Sales Corp.
Minneapolis, Minnesota; St. Louis, Missouri;
Milwaukee, Wisconsin

The J. M. Tull Metal and Supply Co., Inc.
Birmingham, Alabama; Jacksonville, Miami and
Tampa, Florida; Atlanta, Georgia

Whitehead Metals, Inc.
Windsor, Connecticut; Baltimore, Maryland; Cambridge,
Massachusetts; Harrison, New Jersey, Buffalo and
Syracuse, New York; Philadelphia, Pennsylvania

Williams & Co., Inc.
Louisville, Kentucky; Cincinnati, Cleveland, Columbus,
and Toledo, Ohio; Pittsburgh, Pennsylvania

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c. Valves

Crane Valve Co.
Chicago, Illinois

Hoke, Inc.
Cresskill, New Jersey

Jamesbury Corp.
Worcester, Massachusetts

Pacific Valve Company
Long Beach, California

d. Pumps

Byron-Jackson Company
Los Angeles, California

Chempump Div. of Fostoria Corp.
Huntingdon Valley, Pennsylvania

Eco Engineering Company
Newark, New Jersey

La Bour Company
Elkhart, Indiana

Worthington Corp.
Harrison, New Jersey

e. Ejectors

Penberthy Manufacturing Company
Detroit, Michigan

Schutte and Koerting Company
Cornwells Heights, Pennsylvania

f. Sample Thiefs

W & W Manufacturing Company
P. O. Box 9311
Chicago 90, Illinois

Note:

The following equipment is recommended: Model "D"
Golden Thief, aluminum body, 28 mm bottle cap, with
special 3/8" OD x 1/16" wall x (specify length)

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Tygon No. R3604A tubing for use with concentrated hydrogen peroxide. Since it is important that only this special tubing be used in this service, the brand number on the tubing should be checked upon receipt.

g. Hose

Aeroquip Corp.
Jackson, Michigan

American Metal Hose Div.
American Brass Co.
Waterbury, Connecticut

Flexonics Corp.
Maywood, Illinois

Hewitt-Robins, Inc.
Buffalo, New York

Pennsylvania Flexible Metallic Tubing Co.
Philadelphia, Pennsylvania

Resistoflex Corp.
Roseland, New Jersey

Titeflex, Inc.
Springfield, Massachusetts

h. Gaskets

Crane Packing Co.
Chicago, Illinois

Garlock Packing Co.
Palmyra, New York

B. F. Goodrich Co.
Marietta, Ohio

Hercules Rubber & Gasket Corp.
Buffalo, New York

Maybestos-Manhattan, Inc.
Passaic, New Jersey

United States Gasket Co.
Camden, New Jersey

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United States Stoneware Co.
Akron, Ohio

i. Lubricants

Halocarbon Products Co.
Hackensack, New Jersey

Hooker Electrochemical Co.
Niagara Falls, New York

C. CONSTRUCTION MATERIALS

Proper selection of materials for handling hydrogen peroxide is essential. Contact of the peroxide with incompatible metals or incompatible plastics anywhere in the storage system could lead to dangerous conditions. However, aluminum, stainless steel of the 300 series, and certain other materials have only slight effects on the stability of hydrogen peroxide and may be used as material of construction (See Appendix III, Materials Compatibility).

In selecting materials for the fabrication of hydrogen peroxide equipment, the effect of the peroxide on the materials is of considerably less importance than the materials' effect on the peroxide. Nevertheless, this chemical does attack many materials, and the effect must be considered in the design of equipment. Because of its oxidizing action, hydrogen peroxide rusts iron and steel, turns natural rubber tacky, and can cause elastomers to deteriorate, burn, or become impact-sensitive. It also furnishes oxygen and heat to burn combustible materials. These factors may result in operational hazards as discussed in Appendix V.

Appendix III lists materials of construction that have been tested for concentrated hydrogen peroxide. Because construction materials vary widely in their effects on hydrogen peroxide, a standard method of classification has been established that rates these materials according to serviceability. The method of classification is as follows:

Class 1 - Materials that are fully compatible with hydrogen peroxide and suitable for long-time contact, e.g., storage equip. ...nt.

Class 2 - Materials that are satisfactory for repeated short-time contact with hydrogen peroxide prior to storage or use. Contact time prior to storage should be short and should not exceed four hours at 160°F or one week at 70°F prior to use.

Class 3 - Materials that are satisfactory for short-time contact with hydrogen peroxide prior to prompt use. No one

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period of contact should exceed one minute at 160°F or one hour at 70°F.

Class 4 - Materials that are unsatisfactory or hazardous for any use with hydrogen peroxide.

D. DESIGN AND FABRICATION OF HYDROGEN PEROXIDE STORAGE AND HANDLING EQUIPMENT

1. Introduction

Proper design and attention to careful fabrication by approved techniques are next in importance to the proper selection of materials of construction. Naturally, both considerations affect the selection of materials. The time spent in careful development of tank and equipment design, followed by frequent checks on the techniques utilized during fabrication of the tank or item of equipment, will generally result in a product that can be passivated most easily and give the most satisfactory service.

2. Design Practices

a. General Guidelines

In designing an item of equipment for hydrogen-peroxide service, the following general guidelines have been proven to be valuable:

(1) Stress design simplicity in each component and use a minimum number of system components to meet service requirements. Design for easy disassembly of any unit into its component parts for passivation and inspection.

(2) The decomposition rate of hydrogen peroxide is a direct function of the surface area contacted; therefore, the ratio between metal surface and hydrogen-peroxide volume should be minimized, and the surface finish should be as smooth as possible. If the hydrogen peroxide is to be stored in the system for any extended period, a tank-to-system isolation rupture disc is a favorable item to limit the H₂O₂ from contacting the high surface-to-volume-ratio feed lines until the operating period.

(3) In designing a flow system, care must be taken to ensure that peroxide can never be trapped without a vent path or a relief arrangement. Hydrogen peroxide solutions will constantly decompose at a slow but steady rate and, if completely confined, will eventually build up sufficient gas pressure to cause rupture. Ball, plug, and gate valves can trap hydrogen peroxide when closed. If one of these types of valves is to be used, the cavities must be vented.

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(4) All piping systems and items of equipment, especially valves and pumps, should be designed for complete drainage on shutdown. This can be accomplished by providing easily accessible drain-cocks at the low points and by placing equipment containing dams, such as some types of valves, in vertical rather than horizontal positions. A piping system which holds peroxide in stagnant pools, even if properly vented, may corrode excessively even when made of recommended materials.

(5) Dead ends should be avoided. Dead ends are those places which could be filled with peroxide without permitting adequate recirculation of the fluid, as, for instance, in a Bourdon tube pressure gage. Impurities may be swept into the dead end and there accumulate until extensive decomposition of the peroxide results. If dead ends cannot be avoided, they should be placed above the low point in the system so that the peroxide will not collect. The design should allow proper passivation and inspection, and there should be no welds.

(6) Dissimilar metals in contact with H₂O₂ show a tendency for electrolytic (galvanic) corrosion with the more concentrated solutions; even with 90% H₂O₂ the use of dissimilar metals should be avoided. Insulating one metal from the other with a plastic is not always effective in applications where intermittent wetting occurs. If two dissimilar metals must be in contact, the anodic of the two should have a larger surface than the cathodic. In the case of aluminum and stainless steel, which is the combination most commonly encountered, sulfuric-acid anodization and a boiling-water seal of the aluminum surface may reduce the possibility of galvanic corrosion.

(7) Threads and close sliding fits should be minimized on mating parts made from the same or similar materials. Both the stainless steels of the 300 series and the aluminum alloys may gall or seize when mated with themselves. Thus, flanged connections are preferred to threaded ones. Hardened materials such as hard-coat aluminum, 322 stainless steel, or precipitation hardened stainless steel alloys may be used for such service, but experience with these materials is limited. If a design requires mating parts, recommended lubricants and thread compounds should be used.

(8) Low-pressure transfer systems made of aluminum with minor amounts of stainless steel (such as in pump shafts) have been used most extensively with satisfactory results. Use of various aluminum alloys in one system does not appear to result in abnormal corrosion of any of the alloys, but 1060 or 1260 aluminum should be employed wherever possible.

b. Storage Tank Design Practices

In addition to the general guidelines presented in the preceding section, several design practices directly applicable to storage-tank design have evolved. These are described below.

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All tanks which will contain hydrogen peroxide shall be capable of being vented. Storage tanks must have a filtered vent which cannot be inadvertently closed. If possible, a top opening of at least 18-in. diameter should be provided for cleaning and inspection. No tank should have a smaller than 6-in.-dia opening for cleaning and passivation. The large opening of storage tanks should be fitted with a floating manhole cover designed to keep out dirt but free to relieve any pressure that might build up in the tank. A design of this type may prevent a pressure rupture by providing an emergency vent in case of contamination of the hydrogen peroxide. It has been demonstrated in two tests that a 3-1/2- to 4-in.-dia opening will prevent positive pressure build-up in a 30-gal drum containing 25 gal of purposely highly contaminated 90% H₂O₂, so that the H₂O₂ decomposed to dryness in about 2 hr. However, for larger vessels it is probably impractical to have a manhole large enough to guarantee complete relief of pressure build-up from a self-heating decomposition of concentrated hydrogen peroxide.

To avoid possible leaks, storage tanks should have no bottom connections. The contents should be withdrawn from the top through a dip-pipe which extends to the bottom of the tank into a shallow sump formed in the shell. Gage glasses with valved bottom connections are generally used on storage tanks in use with hydrogen peroxide. In special instances bottom outlets have been utilized on 90% H₂O₂ storage tanks, but this practice is strongly discouraged. Processing or hold tanks, which will contain hydrogen peroxide for only a limited time, generally have bottom outlets.

A temperature-monitoring device should be included in storage-tank design. A survey device, which will indicate hot spots as well as average increase in hydrogen peroxide temperature, is the most desirable; however, thermometer bulbs inserted in wells extending into the tank or fastened to the outside of the tank below the normal liquid level and commercial button-type surface pyrometers may also be used. Indicators and/or recorders should be used for maintaining storage-tank surveillance by providing continuous monitoring of both the tank and ambient temperatures. An audio-visual signal should also be provided to give warning at unusually high tank temperature.

c. Stainless Steel Tankage Experience
and Design Practices

The hydrogen-peroxide tankage used in rocket test facilities and certain other applications are often fabricated from stainless steels rather than aluminum. In the design of stainless steel tankage, several practices (in addition to those given in the two preceding sections) and the experience with various stainless steels should be taken into consideration.

Various 300-series stainless-steel alloys are used in fabricating high-pressure hydrogen-peroxide tanks. Stainless Steel 347

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has been used with excellent results. This alloy contains a weld stabilizer that ensures a sound weld and eliminates the need for annealing. Low-carbon 304 L, 316 L, and 321 stainless-steel alloys are also used in such applications.

AM 350 and 355 stainless steels have been used successfully in high-pressure or light-weight tankage. Precipitation hardened 17-7 stainless steel has been used successfully in 76 and 90% hydrogen peroxide systems; however, this material is more difficult to passivate than AM-350 when used in 90 and 98% peroxide systems. All these materials offer yield strengths of about 160,000 psi. Precipitation-hardened alloys should be stress-relieved if the electron-beam welding technique was not employed. The cryogenically prestrained 301 stainless steel offers excellent compatibility with 90 and 98% hydrogen peroxide. The high strength of this material (260,000 psi yield) favors its use for peroxide tankage in flight vehicles and for high-pressure applications.

The following are recommended guidelines for the designing of stainless steel tanks (see also the two preceding sections):

(1) Design the tank with sufficient capacity so that the height of the hydrogen-peroxide level is below the head-attachment weld whenever possible.

(2) Use bright-finish stainless steel plate free from markings.

d. Stainless-Steel Casting Design

The casting of stainless steel in the normal manner may be unsatisfactory for hydrogen-peroxide service even if made of 300-series alloys, which are Class 2 in the wrought or forged form. To improve the compatibility of cast stainless steel, the following is recommended.

Stress design simplicity. Dead-end cores are undesirable. The mold gates should be located so that the slag will float away from surfaces which will contact the hydrogen peroxide. If at all possible, provide for machining or grinding of all surfaces that will be in contact with the hydrogen peroxide. Avoid sharp corners, hidden areas, and any configuration conducive to casting defects. Type 316 stainless steel is the preferred alloy and should have less than 0.10% carbon in the finished casting.

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3. Fabrication Practices

a. General Practices

(1) Welding Aluminum Alloys

Airomatic or Sigma-process automatic inert-gas welding, employing 300 series stainless-steel electrode tip cups, is recommended. Heliarc inert-gas welding has been used satisfactorily, but does have the disadvantage of sputtering tungsten from the electrode into the weld upon initiation and termination of the arc. This condition can be eliminated by striking the arc on a separate piece of the material and carrying the arc onto the work and cut again upon the strike plates. Only thoriated tungsten electrodes and stainless-steel electrode tip cups should be used. The metal-arc process of welding is not recommended because the resulting welds are porous and brittle. However, aluminum tank supports, brackets, and similar items can be fabricated with this technique. Oxygen-acetylene gas welding should be used only in fabricating thin sections such as tubing.

The aluminum welding rod should be of the same alloy as the parent material. If dissimilar alloys are to be joined, the welding rod should have the composition of the harder alloy. The standard 6% silicon and 43S rods are unsuitable for use in fabricating hydrogen peroxide tankage and components.

Welding should be done only by experienced and practiced welders. Chipping and rewelding should be done only if absolutely necessary.

(2) Welding 300-Series Stainless Steels

Inert-gas and metal-arc welding processes are satisfactory. The inert-gas process is preferred because the inert-gas blanket results in a weld much freer of foreign material. In general, thoriated tungsten electrodes are used. Standard procedures for both of these processes should be used. For hydrogen peroxide service, it is necessary that all welds be of high quality, smooth, homogeneous, and free of inclusions and blowholes. Carbide precipitation during welding must be avoided by the use of stabilized alloys (e.g., 347 and 321) or extra-low carbon alloys (304 L or 316 L). Interior welds and weld spatter should be machined or ground smooth. During cleaning and passivation, special attention should be given to stainless-steel welds.

(3) Brushing and Grinding

Internal aluminum welds should not be wire-brushed or machined because impurities may be introduced. However, in some instances, wire brushing may be required. In such a case, a 300 series

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stainless steel brush shall be used and brushing shall be confined to the immediate weld area.

The flux and carbon on stainless-steel welds shall be cleaned from welded areas by a 300-series stainless-steel wire brush. Any inclusions remaining shall be ground out. A clean, white aluminum-oxide abrasive is recommended for the grinding of cast surfaces, welds, and weld spatter on surfaces that will contact concentrated hydrogen peroxide. Carborundum is not recommended because the iron in the carborundum is a catalyst for hydrogen-peroxide decomposition.

(4) Polishing

Mechanical polishing of aluminum alloys is not advisable because of the possibility of introducing incompatible materials which could cause decomposition of the hydrogen peroxide. Electrochemical polishing (anodization) of aluminum is discussed in Section E, 9.

In general, polishing of stainless steels is not necessary but, in certain borderline cases, can improve the compatibility of the metal with the hydrogen peroxide by smoothing the surface. For mechanical polishing, use wet or dry paper with a kerosene lubricant. In general, increasing the smoothness of the surface will decrease the rate of hydrogen-peroxide decomposition.

Electro-polishing of stainless steel improves the steel for hydrogen-peroxide service. For routine hydrogen-peroxide applications, electropolishing is not required because stainless steel is normally recommended only for limited contact time. For special applications, electropolishing of stainless steel might be justified. In such cases, standard electropolishing techniques should be used.

(5) Sandblasting

Sandblasting is not recommended because it produces a porous or pitted surface. Rough surfaces decrease the compatibility of hydrogen peroxide with materials of construction.

(6) Metallizing (Sprayed Metal Coatings)

Metallizing is not suitable in preparing surfaces for hydrogen peroxide service because the hydrogen peroxide may seep behind the metallized coating or an exposed edge and may cause the coating to blister.

(7) Casting Stainless Steel

The following steps should be followed in stainless-steel casting.

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Place mold in such a position that the slag floats to surfaces which will not contact the hydrogen peroxide. Cast with a very hot melt, adding excess of constituents which might burn-out at the casting temperature. Reject castings if there are surface defects which necessitate repair by welding. Grind out small surface cracks or inclusions. Heat-treat castings by soaking at a temperature above 1900°F in a reducing atmosphere for 1 hour per inch of thickness at maximum section. Water- or oil-quench. Proper heat treatment is of vital importance because it is essential that all carbides be retained in solution. If at all possible, machine or grind all surfaces that will contact hydrogen peroxide.

(8) Machining Aluminum and Stainless Steel

Standard good practice for machining of metal parts will be used. A smooth machine finish is important because smooth finishes minimize hydrogen-peroxide decomposition.

(9) Other Techniques

Fabricating techniques, other than those previously discussed, should not be used. Techniques, such as silver or soft soldering, brazing, and the like, can ruin a part for hydrogen peroxide services and can lead to dangerous conditions.

b. Fabrication of Aluminum Storage Tanks

Fabrication of aluminum (1060, 1260, or 5254) storage tanks requires utmost care and attention to recommended procedures because the alloys are soft, easily damaged or contaminated and because a high degree of compatibility is normally required. The recommended fabrication procedures are given below.

Examine the plate material for marks, metal incisions, and embedded particles. Remove these before starting fabrication. Prior to forming the aluminum plates, the steel rolls or press form faces should be covered with heavy kraft paper, leather, or equivalent or, alternatively, the aluminum plate may be covered with heavy kraft paper with adhesive sticking to hold it to the metal surface. During handling and fabrication, care should be continuously exercised to prevent contact of the aluminum surface with iron or steel or marring by any foreign material or object. Re-examine the inner surfaces after forming to ensure that no damage has occurred. Mount the tank section for welding and weld according to the guidelines presented in the preceding section.

Butt-welding from inside and outside is recommended because lap welds offer the possibility of collecting dirt in the cracks. During welding and fabrication, concerted efforts should be made to prevent the inclusion of foreign materials into the aluminum. This can be accomplished in a marked degree if the fabricators wear soft gum rubber shoes and

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cover the area with heavy kraft or equivalent paper. Care should be exercised during welding to ensure proper fusing of the external and internal welds. Gas pockets and other inclusions should be held to a minimum. Inclusions that do occur should not be chipped out unless they are at or near the internal surface.

After welding, nothing need be done to clean and polish the welds prior to passivation. Experience has shown that 1% chemical cleaning during passivation is the most reliable means of preparing a good weld for hydrogen-peroxide storage service.

c. Fabrication of Stainless-Steel Tanks

In addition to the general practices described in Paragraph a, above, several more specific guidelines should be considered in fabricating stainless steel tanks. These are presented below.

Use clean rolling equipment. Tank sections should be from bright-finish plate and free from markings. Head-forming dies should be rust-free and smooth. Use Heliarc or electron-beam welding and be sure all welds are free of inclusions. Remove all weld scale and weld splatters by brushing and grinding as described in Paragraph a. It is often advisable to degrease and passivate the tank head and bottom closures prior to fabrication. This eliminates some difficult passivations.

E. PREPARATION OF MATERIALS AND EQUIPMENT
FOR HANDLING HYDROGEN PEROXIDE

1. Introduction

Surfaces that come in contact with hydrogen peroxide must be specially treated prior to use to prevent decomposition of the hydrogen peroxide. The process which makes the surface inactive is known as passivation.

Passivation consists of treating metal surfaces with acids or other chemicals to form an oxide film on the surface of the metal. The hydrogen peroxide helps to maintain this oxide film. The film between the hydrogen peroxide and the metal surface prevents attack by the hydrogen peroxide and reduces the effect of the metal on the decomposition rate of the hydrogen peroxide. After passivation, conditioning of the surface with hydrogen peroxide tends to render the surface more inert. This improvement continues with use in H_2O_2 service provided no foreign material contacts the surface.

2. Cleaning and Passivation Areas

An area which can be kept clean and free of combustibles should be reserved for the cleaning and passivation of equipment. The

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precautions for handling hydrogen peroxide were listed in Section B. Additional requirements for use of passivating solutions are:

- a. Good ventilation to carry off solvent and acid fumes. Hoods with suction fans should be installed where possible.
- b. Suitable protective clothing; the minimum garb should consist of a face shield or goggles, rubber (acid-resistant) gloves, rubbers, and an apron.
- c. Various sized polyethylene beakers should be provided for the treatment of small parts. These beakers are resistant to all the reagents used in the "pickling" and passivation procedures.

Glass beakers can be substituted for all but the hydrofluoric-nitric solution, but they can be broken easily. The polyethylene beakers must not be used for conditioning or surveillance tests with H_2O_2 unless they are in turn immersed in water.

3. Cleaning and Passivation Solutions

The following cleaning and passivating solutions are required:

a. Detergent

A 1% solution of a powdered commercial detergent such as Dreft, Nacconal, Tide, or Swirl; or a liquid such as Kyro-EO shall be used for cleaning equipment and glassware. Do not use a strong alkaline cleaning solution.

b. Trichloroethylene or Perchloroethylene - Commercial Grade

These solvents are used for degreasing metal equipment which is heavily soiled or very greasy.

c. Sodium Hydroxide (NaOH) Solution (Approx. 1/15 N)
0.25% by Weight

This solution is used for cleaning aluminum equipment. A supply must be available at all times.

d. Sodium Hydroxide (NaOH) Solution, 10% by Weight

This solution is used for cleaning glassware which is heavily soiled or has contained an unknown solution.

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e. Sulfuric Acid 35% by Weight

This solution is used for passivating glassware. Sufficient solution shall be available at all times.

f. Nitric Acid, 42° Baume (Approx. 70% by Weight)

This acid is used for passivating stainless-steel equipment. It should be kept on hand, stored in the containers in which it is received.

g. Nitric Acid, 35% by Weight

This acid is used for passivating aluminum equipment.

h. Hydrogen Peroxide Solution, 35% (Stabilized)

This solution is used, as received, from the manufacturer to "condition" drums and tanks after passivation. If diluted 90% H₂O₂ must be used, a stabilizer should be added to the dilute H₂O₂ and the pH of the solution adjusted. Dilution water must be distilled or de-ionized.

i. Clean Potable Water

This is drinking water and is used for rinsing parts during passivation.

j. Fresh Distilled or Deionized Water

This water is used for rinsing parts after passivation. It must not be stored in aluminum for periods longer than one week prior to or during use.

k. Hydrofluoric Acid - Nitric Acid Mixture, 3:1-10% (Respectively)

This mixture is used for pickling and cleaning stainless steel when rust or other surface contamination exists which cannot be removed by the passivating acid alone.

4. Preparation of Cleaning and Passivation Solutions

a. Detergent Solutions

A 1% solution of a commercial detergent shall be prepared by dissolving 1 part by weight of detergent in 99 parts by weight of potable water, at room temperature.

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b. Sodium Hydroxide (NaOH) Solution, 0.25% by Weight

Dissolve 10 gm of flaked or pelleted sodium hydroxide (99%) in about 1 gal of clean potable water, as follows:

(1) Slowly dissolve the sodium hydroxide in 1/2 gal of water with constant stirring. Heat will be given off during this operation.

(2) Dilute this solution with water to a total volume of 1 gal and mix thoroughly.

The solution can be prepared in a large pyrex beaker and stored in a clean polyethylene container.

c. Sodium Hydroxide (NaOH) Solution, 10% by Weight

Dissolve 10 parts by weight of sodium hydroxide, 99% flaked or pellets, in 90 parts by weight of distilled or deionized water. Heat will be given off during this mixing. The solution can be prepared in a large pyrex beaker and stored in a polyethylene or other suitable container.

d. Sulfuric Acid, 35% by Weight

Add slowly, while stirring constantly, 1 volume of (approximately 95%) sulfuric acid, to 3 volumes of clean potable water. Heat will be given off when mixing the solution. Do not inhale fumes. Always add acid to water.

If a large quantity is to be made, add the acid to the water very slowly to prevent overheating the container. If running water is available, place the beaker in a water bath to dissipate the heat. If mixing is done in a glass container, be careful that the glass does not crack.

Example of dilution quantities:

Acid - 1 quart 95% H₂SO₄

Water - 3 quarts

e. Nitric Acid, 35% by Weight

Add slowly, while stirring, 1 volume of nitric acid (approximately 70%) to 1 volume of clean potable water. Either standard or technical-grade acid can be used. Do not inhale the fumes. Always add acid to water. Example of dilution quantities for 5 gal of 35% by weight nitric acid:

Nitric acid (70%) - 2-1/2 gal

Water - 2-1/2 gal

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f. 3 Wt % Hydrofluoric Acid and 10 Wt % Nitric Acid

Add slowly, and with constant stirring, 1 volume of hydrofluoric acid (approximately 52%) and 2 volumes of nitric acid (70%) to 16 volumes of clean, potable water. Use extreme care in handling hydrofluoric acid. Example of dilution quantities required for a 10-gal solution of 3% hydrofluoric acid and 10% nitric acid:

Hydrofluoric acid (52%)	- 2 qt
Nitric acid (70%)	- 1 gal
Water	- 8 gal

5. Storage Containers for Cleaning and Passivation Solutions

The cleaning and passivation solutions must be stored in proper containers. The type of equipment required for storing these solutions is listed below.

a. Detergent Solution

Use a non-rusting container, preferably one that can be heated to 120°F (49°C). A lid should be provided to keep out dirt.

b. Trichloroethylene and Perchloroethylene

Use a galvanized-iron, black-iron, or steel container. The entry of water into the chlorinated solvent must be prevented to preclude the formation of acids and subsequent corrosion of the container. A lid or closure should be provided to keep out dirt and to prevent the solvent fumes from escaping.

c. Sodium Hydroxide Solution

Use a stainless steel drum or polyethylene container which has been previously washed with a detergent solution and rinsed with clean potable water.

d. Sulfuric Acid

Use a polyethylene or polyethylene-lined container or the glass carboys in which the acid is received. A lid must be provided for out-of-doors storage. Heated storage may be necessary depending on the concentration of the acid and the winter temperature of the locality where stored.

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e. Nitric Acid

Use a polyethylene-lined or an AISI 300-series stainless-steel container. Provide a lid to keep out dirt and to confine the acid fumes.

f. Hydrogen Peroxide, 35%

Use a pure-aluminum (1060), aluminum-alloy (5652 or 5254), or polyethylene container. This container must be vented at all times, and the vent line must be provided with a porous stone filter or plastic vent to keep out dust or dirt. A hydrogen peroxide shipping drum is a convenient container; however, when hydrogen peroxide is once removed, do not return the peroxide to the original drum or container.

g. Potable Water, Distilled Water, or Deionized Water

Use a non-rusting container or piping system. (Avoid copper lines and copper equipment.) Keep storage time to a minimum, preferably less than one week.

h. Mixture of Hydrofluoric Acid and Nitric Acid

Use a polyethylene-lined container. Provide a lid to keep out dirt and confine the acid fumes.

6. Passivation of Aluminum Parts

It is recommended that aluminum and aluminum-alloy parts and valves be treated as follows:

a. Degrease by agitating in a 1% detergent solution. Scrub with a brush. The solution shall be warmed to about 120°F (49°C) and should either be pumped through the tubing and piping or the parts containing the solution should be agitated.

b. Rinse well with potable water. All subsequent handling shall be done with gloved hands or clean tongs.

c. Immerse or fill the part with 0.25% sodium hydroxide for 15 to 20 min at room temperature. Remove parts and rinse in potable water. Hydrogen gas is given off. No smoking or open flame is permitted within 25 ft of this operation.

d. Immerse or fill part with 35% nitric acid for 1 hr at room temperature.

e. Rinse thoroughly with distilled or deionized water.

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f. Condition the part with hydrogen peroxide for 3 to 4 hrs and note the rate of hydrogen-peroxide decomposition.

(1) Small parts should be immersed in hydrogen peroxide solution of a concentration identical to that the part is to handle.

(2) Large parts, such as valve bodies, tubing or piping, should have the outlet blanked off and should be filled with hydrogen-peroxide solution of a concentration identical to that the part is to handle.

(3) During conditioning, watch closely for heating.

g. If excessive decomposition is observed, i.e., if many bubbles or gas streamers are seen or if heating of the part occurs, the part should be removed from the hydrogen peroxide, washed with water and inspected. If no defect can be found, Steps d, e, and f should be repeated. If the hydrogen peroxide continues to decompose excessively after the second treatment, the part should be rejected. If only small areas of parts may actually come in contact with hydrogen peroxide in final assembly, apparent activity from surfaces not normally exposed should not be cause for rejection.

h. Reject any parts which discolor the hydrogen peroxide.

i. Remove the part from the hydrogen peroxide, flush with distilled water, and inspect. Return any parts which show blackening, rust streaks, or signs of corrosion.

Note: The hydrogen peroxide used for conditioning should be disposed of immediately after completion of this operation. Dilute it with at least 10 volumes of water prior to discarding. Since it may be contaminated, do not handle this H₂O₂ in a system that will be used for fresh H₂O₂.

j. Small parts are air-dried or oven-dried (if no plastic inserts are present) after conditioning. Keep dust and dirt from the parts during drying.

k. Reassemble the parts, and package (see Paragraph 14).

7. Passivation of Aluminum Tanks

It is recommended that aluminum tanks, particularly storage tanks, be treated as follows:

a. Degrease by washing with a 1% detergent solution. Exceptionally greasy tanks should be degreased first with trichloroethylene or perchloroethylene and then washed with the detergent. Rinse thoroughly with clean, potable water.

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b. Pump clean potable water into the tank and fill the tank approximately one-half full. Pump or pour the required nitric acid into the tank being treated. Fill the remainder of the tank with clean potable water.

c. Use the quantities shown in the following table:

QUANTITIES OF ACID AND POTABLE WATER
FOR PASSIVATING TANKS

Tank Capacity, gal	First Water Addition, gal	70% HNO ₃ , gal	Final Water Addition, gal
100	45	5	50
500	225	25	250
1,000	449	51	500
2,000	898	102	1,000
4,000	1,796	204	2,000
5,000	2,245	255	2,500
6,000	2,694	306	3,000
8,000	3,592	408	4,000

The resulting solutions are approximately 5% nitric acid.

d. Allow the acid solution to remain in the tank for one to two days. Leave all nipples and manholes open but, if the tank is out-of-doors, protect the tank from dirt by covering the openings with polyethylene or vinyl sheet. After one to two days, transfer the acid to a spare tank or to a second tank to be passivated. For economic reasons, the same batch of acid solution may be used for the treatment of as many as three tanks depending upon the amount of dirt and grease in the acid. The solution shall then be discarded. Do not store the nitric acid in aluminum tanks.

e. Rinse the treated tank with clean potable water and dry with a clean, lint-free cloth (clean rubbers should be worn to prevent scratching the bottom of the tank). Examine the inside of the tank for any iron spots. If any are present, dig them out with a knife point. If there are any unpassivated spots, scrub these with detergent to remove grease which may have prevented the acid from contacting the metal surface.

f. Repeat Steps b through e.

g. If the interior of the tank now has a uniform dull, velvety finish, the tank is satisfactorily passivated. Otherwise, repeat the treatment.

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h. If possible, the tank should be conditioned by filling with stabilized 35% hydrogen peroxide for one to three days before filling with concentrated hydrogen peroxide.

i. During conditioning, the passivity of the tank surfaces can be determined by observation. If there is no steady bubbling, if no gas streamers are present in the tank, and if the hydrogen peroxide solution is quiet and cool, the tank is said to be compatible.

j. Pump the 35% H₂O₂ solution out, rinse the tank with distilled or deionized water, and pump in the concentrated hydrogen peroxide. If the tank will remain empty for more than a week, it should be dried with a clean, lint-free cloth after washing.

Note: If a tank is found to have satisfactory compatibility during conditioning, the 35% H₂O₂ used may be retained in a proper container for additional conditioning use. The stability of the solution should be checked. If the tank causes an unsatisfactory rate of decomposition of the 35% H₂O₂, the H₂O₂ must be checked for stability before it is retained for further use.

k. On the first filling with concentrated hydrogen peroxide, strict surveillance should be maintained for 16 to 24 hrs to note any undue temperature rise of the tank or excessive gassing of the hydrogen peroxide.

This method of passivating aluminum tanks for H₂O₂ storage has been in use for the last 30 years with very satisfactory results. However, a relatively new technique should also be mentioned which entails the use of "sprays" from a suitable manifold temporarily positioned within the tank. Preliminary tests results have been promising, but the lack of proven experience in the field with concentrated H₂O₂ prohibits the blanket recommendation of this method.

Note: Do not store distilled or deionized water in an aluminum tank because slime formation may render the tank unsuitable for H₂O₂ storage.

8. Accelerated Passivation of Small Aluminum Containers

In treating small tanks and drums, a modified procedure may be followed to reduce the time required for passivation. The following method is suggested:

a. Treat the tank with sodium hydroxide of about 0.25% concentration by standing the tank first on one end and then the other, and finally rolling the tank for 5 to 10 min for each surface. Vent and dump immediately and wash thoroughly with potable water. Do not allow the hydroxide to dry in the tank. Smoking or open flames are not permitted within 25 ft of this operation because hydrogen gas is liberated.

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b. Add 35% nitric acid to the tank by hand pump or by a small, motor-driven pump to fill 1/2 of the tank.

c. Seal the tank and roll intermittently for one to two hrs at room temperature. Alternately, the tank may be filled completely with 35% nitric acid and allowed to stand for one to two hr at room temperature.

d. Rinse thoroughly with distilled water.

e. Condition the tank with stabilized 35% hydrogen peroxide as described in Paragraph 7,h.

9. Anodization of Aluminum Alloys

Anodization, or anodic oxidation, is the process by which the thickness of the oxide naturally present on aluminum and its alloys is increased (perhaps a hundred times) and its protective value correspondingly improved. All aluminum and aluminum alloys for use with hydrogen peroxide should be anodized, if practical.

Sulfuric-acid anodization has been used successfully. Anodization procedures have been developed by various companies for use in H₂O₂ systems, but the procedure given in Military Specification MIL-A-8625 should be followed. After the process is complete, immerse the parts in boiling, distilled water for about one hour to seal the pores in the metal. No other sealing agent shall be used because it may have a catalytic effect upon hydrogen peroxide.

Anodized parts should be handled carefully to keep them clean and free from scratches. Prior to use they should be degreased, rinsed with distilled water, and conditioned in hydrogen peroxide. Do not treat with sodium hydroxide; such treatment will remove the anodized surface.

If compression-sealing fittings such as aircraft AW with 37-degree flares are used, the sealing surfaces must be stripped to ensure a leak-tight seal. Electrodes of copper wire, wrapped spirally with Teflon, have proved satisfactory for anodizing of small-bore tubing. Localized heating of the anodizing solution due to improper circulation will result in checked surfaces.

Hydrogen peroxide has been stored in anodized aluminum tanks for up to two years with satisfactory results.

10. Passivation of Stainless-Steel Parts

It is recommended that all new AISI 300-series stainless-steel parts, valves, small tanks, tubing, piping, springs, etc. be treated individually as follows:

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a. Disassemble the units into their component parts except for plastic inserts that might be damaged by removal.

b. Degrease by agitating in a 1% detergent solution. Scrub with a stiff brush. The solution should be warmed to about 120°F (49°C), if possible. The detergent solution may be either pumped through, or the parts should be agitated while the solution is standing in them. Exceptionally greasy parts should be degreased first with trichloroethylene, allowed to drip dry, and then washed with detergent.

c. Flush with clean potable water immediately after the detergent wash. From this point on, the parts should be handled with gloved hands or clean stainless-steel-tongs.

d. Immerse or fill with 70% nitric acid for four to five hr at room temperature. Rinse thoroughly with distilled water.

e. Condition the part with hydrogen peroxide for three to four hr and note the rate of hydrogen-peroxide decomposition:

(1) Immerse small parts directly in hydrogen-peroxide solution of a concentration identical to that the parts are to handle.

(2) Completely fill small tanks and large parts, such as valve bodies, tubing, or piping, with hydrogen-peroxide solution of a concentration which these parts are to handle.

(3) During conditioning watch closely for heating of the part or for decomposition of the hydrogen peroxide.

f. If excessive decomposition occurs, i.e., if many bubbles or gas streamers are observed or if heating of the part occurs, the part should be removed from the hydrogen peroxide, washed with fresh water, and inspected. If no defects are found, Steps d and e should be repeated. If the hydrogen peroxide continues to decompose excessively after the second treatment, the part should be pickled as described in Paragraph 12. If only small areas of parts may actually come in contact with hydrogen peroxide in final assembly, apparent activity from surfaces not normally exposed should not be cause for rejection.

g. Look for discoloration of the hydrogen peroxide; it should be colorless (in very large volumes, it has a slight blue cast). If the hydrogen peroxide is discolored discard it promptly. Pickle any stainless steel part which discolors the hydrogen peroxide with 3% HF-10% HNO_3 solution as described in Paragraph 12. Discoloration is caused by impurities leached (dissolved) from the stainless steel. The table below shows possible causes for hydrogen peroxide discoloration.

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CAUSES FOR H₂O₂ DISCOLORATION

Color	Cause
Light pink to purple	Chromium
Blue	Copper
Yellow	Iron or titanium

h. Remove the parts from the hydrogen peroxide and rinse with distilled or deionized water. Inspect for rust or other corrosion. If rust is found, repeat Steps d and e. If rust persists, pickle part as described in Paragraph 12. Note: Dilute and discard the hydrogen peroxide immediately after the conditioning period is completed. (See note, Paragraph 6,1).

i. If there are no unfavorable results, the parts are considered to be conditioned for H₂O₂ service.

j. Small parts are either air-dried or oven dried after conditioning. If plastic inserts are present, the oven temperatures must be well below the melting point of the plastic. Take care to prevent dust and dirt from contacting the parts during drying. Tanks must be dried unless used immediately; air-drying is sufficient.

k. Reassemble the parts and package as described in Paragraph 14.

An alternate passivation procedure can also be used on hardened stainless steel such as Armco 17-7PH. This procedure consists of immersion in 2% Na₂Cr₂O₇.2 H₂O - 20% HNO₃ solution for 1/2 hr at 120 to 130°F, followed by flushing with clean potable water, distilled water, and drying.

11. Passivation of Stainless-Steel Tanks

a. Degrease by washing with a 1% detergent solution. Exceptionally greasy tanks should first be degreased with trichloroethylene or perchloroethylene and then be subjected to the detergent wash. Rinse thoroughly with clean, potable water.

b. Examine the tank for any welding scale, rust, or other inorganic contaminant. If any is noted, brush the welds with an AISI 300-series stainless-steel brush and then fill the tank with a pickling solution of 3% hydrofluoric acid and 10% nitric acid for two to three hr at room temperature (65 to 70°F). Remove and rinse with clean tap water and brush welds again with the stainless-steel brush. After brushing, the debris must be cleaned out and care must be taken to ensure that wire bristles are not left sticking in the welds.

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c. Fill the tank at room temperature with nitric acid of about 70% concentration for four to five hr or with 35% nitric acid for 16 to 24 hr. Rinse with distilled water.

d. If possible, condition the tank by filling with stabilized 35% hydrogen peroxide for one to three days before filling with high-strength hydrogen peroxide.

e. During conditioning, the passivity of the tank surfaces can be determined by observation. If no steady bubbling occurs, no gas streamers are noticed, and the hydrogen peroxide solution is quiet and cool, the tank is said to be compatible.

f. The 35% hydrogen peroxide may be pumped out, the tank rinsed with distilled or deionized water, and the concentrated hydrogen peroxide pumped in. For possibility of retaining the 35% H₂O₂ after conditioning, see Note, Paragraph 7,j.

g. On the first filling with concentrated hydrogen peroxide, a strict surveillance should be maintained for 16 to 24 hr to note any undue temperature rise of the tank or excessive gassing of the hydrogen peroxide.

12. Pickling of Stainless Steel

Some stainless-steel parts and tanks will not respond to the passivation treatment given above. Use stainless-steel surfaces, stainless-steel welds, and rusted surfaces invariably require an acid etch before passivation. A part which has not satisfactorily passed the conditioning step because of excessive hydrogen peroxide decomposition, discoloration of the hydrogen peroxide, or rusting should be treated as follows:

a. Apply petrolatum to all gasket and other surfaces that may be damaged by the HF-HNO₃ solution.

b. Immerse the part in 3% hydrofluoric acid-10% nitric acid for 30 min at 100°F or for a maximum of 3 hr at 65 to 70°F. Keep the hydrofluoric acid-nitric acid away from sealing surfaces; if this is not practical, make a paste of 3% hydrofluoric acid-10% nitric acid in graphite and apply the paste to the surfaces to be treated.

c. Flush with potable water. Scrub with a stiff brush to remove welding scale and the paraffin coating.

d. Apply the nitric-acid passivation procedures given in Paragraphs 10 and 11. If the part still is not passive, repeat Steps a through d. If after the second treatment the part still is not passive, it must be rejected.

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13. Cleaning of Plastics

All plastic parts, O-rings, and gaskets can be cleaned as follows:

a. Wipe all parts as clean as possible with a lint-free rag before beginning operations.

b. Degrease by agitating the part in a 1% detergent solution. The solution should be warmed to about 120°F, but should not be heated to boiling because of possible damage to the plastic.

c. Rinse thoroughly in distilled or deionized water.

d. Immere into or fill the plastic parts with 20 wtp% nitric acid at 68 to 72°F for one hr and rinse thoroughly with water.

e. Submerge the plastic part for 16 to 24 hr in hydrogen peroxide of a concentration identical to that it is to handle and note the rate of hydrogen-peroxide decomposition. Flush with distilled water and inspect. If the part is satisfactory, it can then either be assembled into its unit or dried and packaged as described in the following paragraph.

14. Packaging

All passivated parts other than those to be used immediately should be sealed against dust and dirt and properly labeled. It is suggested that the label give the name and number of the part, the date when passivated, and the name of the inspector. Small units may be stored in sealed polyethylene or Vinyl bags. All external threads should be protected and all openings should be closed with tight-fitting polyethylene plugs. These plugs are readily available commercially. Care must be taken to ensure removal of the plastic plugs prior to installation of the part. Prior to sealing a bag or a large part, all air should be flushed with dry nitrogen gas to remove atmospheric moisture.

15. Glassware Passivation

Prior to use, all glassware, including thermometers and hydrometers, should be cleaned as follows:

a. If heavily soiled, immerse in 10% sodium hydroxide solution for one hr at room temperature. If the glass is relatively clean, use a detergent instead of sodium hydroxide because the latter may actually decrease the inertness of the surface to hydrogen peroxide.

b. Rinse in clean potable water.

c. Immere in 35% sulfuric acid for at least one hr at room temperature.

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- d. Rinse in distilled water.
- e. Air-dry or dry in an oven at 110°C (230°F).
- f. Passivated glassware can be stored, ready for immediate use by covering the opening with aluminum foil.

16. Passivity Checks

After tanks and component parts have been passivated and conditioned with hydrogen peroxide, they are ready for hydrogen-peroxide service. The first time an assembled system or tank is filled with concentrated hydrogen peroxide, it will be held under surveillance, i.e., carefully watched for a specified period of time to determine whether or not any decomposition occurs. This surveillance period varies depending upon the type of equipment and its end use. The concentration of the hydrogen peroxide may be determined at the time of filling and again after a specified surveillance period. A small loss is to be expected when the equipment is initially filled.

To determine the decomposition rate of hydrogen peroxide for a specific item of equipment, the conditions affecting the decomposition rate must be known. The most important ones are:

a. Temperature - The rate of decomposition will increase about 1.6 times for each 10°F rise in the temperature of the solution (2.4 times for each 10°C rise).

b. Surface Area - Nearly all of the hydrogen-peroxide decomposition occurs on the surface of the container or piece of equipment in the solution. Very little decomposition occurs in the body of the solution. Therefore, the amount of surface in contact with a specific volume of liquid has an important effect on the decomposition rate. In general, the rate of decomposition is directly proportional to the ratio of wetted surface and volume of solution. It is evident then that a threaded bolt will normally decompose hydrogen peroxide at a much faster rate than would a smooth rod of the same diameter and length.

c. Type of Surface - A stainless-steel surface will normally decompose hydrogen peroxide three to ten times faster than a pure aluminum surface even though both surfaces are correctly passivated. In general, the smoother the surface of a specific metal the less will be the rate of hydrogen peroxide decomposition.

17. Passivity Checks of Individual Components of Flow Systems

For some purposes, a quantitative passivity check of components of flow systems other than tanks may be desired. Three criteria have been provisionally established to determine the suitability of a component for H₂O₂ service: (1) loss of liquid concentration, (2) temperature rise during heating, and (3) change in porosity of the metal after testing. Testing should be done with 30% solution which is kept at a temperature of at least 70°F for a period of 24 hrs. The following limits are suggested:

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- a. Maximum loss of H₂O₂ concentration: 0.7%.
- b. Maximum temperature rise above ambient during the test: 5°F.
- c. Minimum stability of the H₂O₂ following the test: 90% of active oxygen content retained after holding at 212°F for 24 hr.

Experience in applying these criteria may result in modifications and additions based on the factors of ambient temperature, surface area-to-volume ratio, and type of surface.

18. Passivity Checks of Hydrogen-Peroxide Flow Systems

A hydrogen peroxide system made from individually passivated parts may be considered passivated. However, in assembling a hydrogen-peroxide flow system care must be taken to prevent any foreign matter, such as incompatible pipe dope, metal chips, or greasy rags, from entering. After assembly, washing out with distilled or deionized water is recommended before the system is considered ready for hydrogen-peroxide service. This water must be removed completely from the system after washing. The first time the complete system is filled with hydrogen peroxide, it should be held under surveillance for six hours. As these systems generally include some Class 2 and Class 3 material, some decomposition of the hydrogen peroxide is to be expected during this time. The following should be measured:

a. Temperature - The temperature of all parts on the outside of the hydrogen-peroxide system, including tank, piping, valves, and similar items, can be assessed through feeling by hand. A temperature survey system such as manufactured by Taylor Instrument Co. (vapor-actuated temperature device), consisting of a capillary tube which wraps around the storage vessel or piping system, can be used to remotely determine "hot spots" that may exist. Inaccessible areas can also be measured by thermocouples.

b. Rate of Decomposition - Use one of the procedures given in Paragraph 17. The following criteria will be used to determine if a system is passive:

(1) If local hot spots (approximately 5°F warmer than surrounding areas) are found, that component of the system will be replaced and the passivity test repeated. The component which has been removed will be returned for repassivation.

(2) If the rate of decomposition is excessive and the cause for the high rate cannot be attributed to one or more components of the system, the entire system must be repassivated. An excessive rate of decomposition is that rate which would reduce the hydrogen peroxide concentration to a point where it would fail to stabilize the end of the piping system for a specific end use after a specified time, or would cause the hydrogen peroxide to heat 5°F above ambient within that time.

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19. Passivity Checks of Concentrated H₂O₂
Aluminum Storage Tanks

Aluminum tanks which are to be used for long-time storage of hydrogen peroxide should be held under surveillance for at least 24 hr, and preferably 72 hr, the first time they are filled with concentrated hydrogen peroxide. During this period the tank shall be observed hourly, and the temperature of the solution and of the surrounding air should be measured by thermocouples or thermometers. In addition, the temperature of all parts on the outside of the tank can be assessed through feeling by hand.

The rate of decomposition of the H₂O₂ shall be determined by sampling the hydrogen peroxide at the start and at the end of the surveillance period, and by measuring and comparing the hydrogen-peroxide concentration of the samples.

A tank is considered to be passive if it passes the standard observations, and if the rate of hydrogen-peroxide decomposition is not greater than the specified acceptable limit. The table below gives normal and abnormal rates of decomposition for drums and bulk tanks:

H₂O₂ DECOMPOSITION RATES FOR ALUMINUM
LONG-TERM STORAGE CONDITIONS

<u>Size of Container</u>	<u>Decomposition Rate, % year</u>	<u>Normal Rate, %/24 hr</u>
30 gallons (drum size)	1 to 2	0.0027 to 0.0054
500 gallons or larger	1 or less	0.0027 or less

If the tank fails in any of the criteria listed above, it must be repassivated. The H₂O₂ to be removed from an improperly passivated tank must be checked for stability before being transferred to another tank.

When the H₂O₂ is stored in specially treated aluminum tanks, the decomposition rate is considerably less than that listed in the preceding table. This condition is improved as the H₂O₂ concentration increases.

F. STORABILITY OF HIGH-STRENGTH HYDROGEN PEROXIDE

The storability of hydrogen peroxide is dependent upon the magnitude of each of three basic sources of decomposition: (1) liquid-phase decomposition caused mainly by catalytic metal ions, (2) liquid-phase decomposition on submerged surfaces, and (3) gas-phase decomposition on surfaces above the liquid. Homogeneous vapor-phase decomposition is negligible at normal storage conditions. The magnitude of the first source of decomposition is dependent on temperature and the nature and concentration of impurities and stabilizers, but is independent of surface area or condition of the surface (except as they may contribute to the concentration of impurities). The magnitude of the second and third sources of decomposition are dependent upon temperature,

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material of construction and its preparation (chemical and physical), and the relationship between surface area and volume of the liquid. From the foregoing it can be seen that the acquisition of meaningful storability data is difficult and that the interpretation of data obtained mostly as a matter of circumstances is dangerous.

(c) Shell Development Company is currently involved in a program specifically directed toward improving the storability of high-strength hydrogen peroxide (1) thru (5). Their principal lines of attack are: (1) the development of a simple process for final purification of the peroxide immediately prior to filling the storage container, (2) the development of an improved liquid-phase decomposition inhibitor system, and (3) the assessment of prospective container materials for compatibility with long-term peroxide storage. The most practical and successful results to date in each area of attack are: (1) passing the current, commercially produced hydrogen peroxide through a bed of insoluble hydrated stannic oxide, (2) using half neutralized sodium stannate prepared in hydrogen peroxide as an inhibitor, and (3) using electrolytically deposited tin as the container surface which contacts the peroxide. The success of this program is indicated in the following paragraphs where the storage history of hydrogen peroxide is presented.

1. Storability of 90% Wt Hydrogen Peroxide

(u) Although much of the storability information available on 90% H₂O₂ has been gained via circumstances rather than plan, sufficient data are available to define approximate levels of decomposition that can be anticipated in several materials under normal handling and storage conditions and those that can be expected when special care, treatments, and/or materials are utilized. The available data are presented in the following table:

(c) STORABILITY OF 90% WT H₂O₂

Type H ₂ O ₂ Process	Normalized Form.	Material	Storage Conditions			Decomp. Rate, % H ₂ O ₂ /hr	Ref.
			Vol.	Duration	No.		
Electrolytic	No	Ambient 1060 Al	25000	4½ to 12		Undetectable	8
Electrolytic	No	Ambient 1060 Al	8000	8 to 9		0.27 and 0.75, avg of 2 = 0.51	8
Electrolytic	No	Ambient 1060 Al	30	13 to 34		0.15 to 2.33, avg of 12 = 1.01	6
Electrolytic	No	Ambient 5652 Al	30	13		0.42 and 0.54, avg of 2 = 0.48	6
Electrolytic	No	Ambient 5254 Al	30	13		0.09 and 0.40, avg of 2 = 0.25	6

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Process	Type H_2O_2	(c) Storage Conditions		Volume gal	Duration hr	Decomp. Rate, % H_2O_2/yr	Ref.
		Stabilized	Temp.				
Electrolytic	No	Ambient	5052 Al	30	13	0 and 2.7, avg of 2 = 1.35	8
Electrolytic	No	Ambient	Teflon	1	4 to 5	1.3 and 2.2, avg of 2 = 1.75	7
Electrolytic	Yes	Ambient	1060 Al	30	63	0.29 and 0.62, avg of 2 = 0.45	6
Electrolytic	Yes	77°F	1260 Al	5	2.9	0.58 and 0.62, avg of 2 = 0.60	4
Electrolytic	Yes	Ambient	Teflon	1	2 to 3	1.7 and 2.0, avg of 2 = 1.85	7
Organic	No	77°F	1260 Al	5	2.7 to 3.1	0.78 to 0.85, avg of 3 = 0.83	4
Organic	Some tin added	Ambient	High-purity aluminum	30	13	0.45, 1 sample	2
Organic	Yes	77°F	1260 Al	5	1.3 to 2.9	0.12 to 0.18, avg of 3 = 0.15	4
Organic	Yes	77°F	5052 Al	5	1.3	0.63, 1 sample	4
Organic	Yes	104°F	5052 Al	5	1.9	1.66, 1 sample	4
Organic	Yes	77°F	Kel-F	5	2.5	0.24 and 0.26, avg of 2 = 0.25	4
Organic	Yes	77°F	Pyrex	5	---	0.04	5
Organic	Yes	104°F	Pyrex	5	1.8	0.14, 1 sample	4

(u) On the basis of the preceding data it appears that a decomposition rate of less than 1% /yr can be realized without difficulty at ambient temperature with either electrolytic or organic-process H_2O_2 in aluminum-alloy (1060, 1260, 5052, or 5254) tanks as small as 5 to 30 gal, even when the H_2O_2 is not stabilized. In large tanks (3000 gal) the decomposition becomes difficult to detect. Stabilization appears to decrease decomposition rates in metals by a factor of 2 to 5. Decomposition rates as low as 0.01%/yr appear attainable at ambient temperature.

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2. Storability of 98% Wt Hydrogen Peroxide

Very little storability information is available on 98% wt H₂O₂. The data found are presented in the following table:

STORABILITY OF 98% WT H₂O₂

Type H ₂ O ₂		Storage Conditions				Decomp. rate, % H ₂ O ₂ /yr	Ref.
Stabilized	Process	Temp.	Material	Volume, gal	Duration, hr		
No	Electrolytic	Ambient	1060 Al	~30	33	0.044 to 1.25, avg of 12 = 0.39	6
No	Electrolytic	Ambient	Teflon	~ 1	~ 4	1.53 (single sample)	7
No	Electrolytic	Ambient	Farrellok soln. treated Teflon	~ 1	~ 4	1.27 to 1.69, avg of 2 = 1.48	7
Yes	Electrolytic	Ambient	Teflon	~ 1	5	0.60 to 1.13, avg of 2 = 0.86	7

A comparison of the storability data for unstabilized electrolytic 90 and 98% H₂O₂, presented in the two preceding tables, indicates that 98% H₂O₂ is more storabile than 90% H₂O₂ by a factor of approximately 2.6, all other factors being constant. A similar direct comparison for organic-process H₂O₂ is not available, but Shell Development concludes that hydrogen peroxide of 95 to 97% concentration can be prepared with a high degree of purity and can be stabilized to the same degree as 90% H₂O₂, i.e., to give decomposition rates of only 0.04 to 0.05%/day at 212°F(4). Three-month storage tests at 68°F in 30-gal shipment drums on unstabilized and stabilized 98% H₂O₂ indicate that the addition of stabilizers decreases decomposition rate by a factor of about 2.7(7). This improvement in stability is in line with that seen in 90% H₂O₂ when stabilizers are added.

G. SELF-HEATING IN CONCENTRATED-HYDROGEN-PEROXIDE STORAGE TANKS

Self-heating in storage tanks presents no problem as long as high-quality hydrogen peroxide is initially introduced into a storage tank which is properly prepared and properly designed to prevent contamination. However, self-heating can occur when these precautions are not observed or are subsequently voided by accident. In the following paragraphs the onset of

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potentially dangerous self-heating is described and procedures for dealing with self-heating are given.

(9) Bartlett has analytically studied the conditions which constitute a dangerous situation (i.e., one requiring corrective measures). He concluded from his study that if hydrogen peroxide, by virtue of decomposition, attains a temperature about 20°F above that of the surroundings, corrective action is required. The time available for taking corrective measures is dictated by the decomposition rate existing at the temperature attained by the peroxide when it is 20°F above the temperature of the surroundings. The greater the decomposition rate, the more urgent it is to take corrective measures.

(10) Shanley considers keeping time-temperature records on large tanks of concentrated hydrogen peroxide to be advisable and recommends that corrective actions should be initiated if the temperature of the hydrogen peroxide is more than 2 or 3°C (3.6 or 5.4°F) above the maximum ambient temperature or if a rapid rise in temperature occurs (0.5°C or more per hour). These conditions appear somewhat more stringent than the 20°F temperature difference criterion suggested by Bartlett, but Shanley's criteria for starting corrective measures are deemed to be more advisable because they would extend the time available to control the situation.

Shanley recommends the following procedures for controlling self-heating. In the early stages of self-heating, the decomposition can be curbed by the addition of stabilizers or by cooling with water. It is advisable to stock packages of emergency stabilizers at large storage locations. External cooling with water sprays may dissipate heat at least ten times as fast as air convection, with obvious advantages in bringing a self-heating tank under control. Internal cooling with clean water, thus diluting the peroxide, is also a very effective means of control.

While attempting to control a self-heating tank, a careful time-temperature record should be kept to provide a running record of the effectiveness of the control means. In projecting the time-temperature curve into the future, it is well to bear in mind several approximations made. Most of these approximations overestimate the hazard and underestimate the time before eruption. However, at least two factors may operate in the opposite direction: (1) possible breakdown of stabilizers as the reaction proceeds and (2) the formation of a blanket of gas bubbles on the interior surfaces, which might reduce heat transfer to the surroundings.

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APPENDIX V

HAZARDS AND SAFETY OF HYDROGEN PEROXIDE (u)

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FIGURE LIST

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2 Burning Rates of 90% wt Hydrogen Peroxide	14

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APPENDIX V

HAZARDS AND SAFETY OF HYDROGEN PEROXIDE

A. SENSITIVITY

1. Impact

(u) Shell Development Company⁽¹⁾ reports that the Germans investigated the hydrogen peroxide-water system using an impact tester. The device is not described, although there are indications that a weight of 2 to 5 kg was dropped from a height of 85 cm or more. No explosions were obtained, neither with various solutions nor with 100% hydrogen peroxide. A sample of solid hydrogen peroxide likewise did not explode. Ellinger et. al.⁽²⁾ tested 90% hydrogen peroxide using a 200 gm weight dropped 350 cm and obtained no explosions. Impact tests performed by Becco and Shell Development Company with solutions containing up to and including 100% hydrogen peroxide similarly gave no explosions⁽¹⁾. Bloom and Brunsvold⁽³⁾ tested high-purity hydrogen peroxide (>98%) with a modified Bureau of Mines impact tester and achieved no explosions at temperatures up to 212°F (100°C) and impacts of 300 kg-cm.

(c) No explosions were obtained in impact tests of Kel-F or Teflon in contact with liquid hydrogen peroxide (85 to 90%) at temperatures as high as about 400°F. The plastics were shreds, filings, or powdery dust, and in some instances were mixed with aluminum or iron filings. On the other hand, dispersions of 200 mesh polyvinyl chloride (PVC) in 90 or 96.7% hydrogen peroxide exploded in the impact tests at room temperature. This difference in behavior is probably due to the C-H bonds which exist in PVC but are absent in the completely halogenated Kel-F and Teflon⁽⁴⁾.

2. Adiabatic Compression

(c) Adiabatic compression tests with 70% hydrogen peroxide at ambient temperature and at 160°F show the material to be insensitive at compression rates as high as 231,000 psi/sec⁽¹⁾. Somewhat similar tests with 90% hydrogen peroxide (90% H₂O₂ driven with 2000 psi air pressure against the closed end of a 1.250-in.-ID-pipe) have been reported by Ellinger⁽²⁾. He obtained no explosion in these tests or in tests in which the peroxide was driven through a 0.250-in. hole in the end of the pipe. From limited testing Rocketdyne concluded that 90% H₂O₂ is insensitive to adiabatic compression at all initial liquid temperatures up to 250°F and at pressurization rates up to about 200,000 psi/sec⁽⁵⁾⁽⁶⁾.

3. Sensitivity to Gunfire

(u) The hydrogen peroxide-water system has been tested for sensitivity by gunfire. No explosion took place when the Germans fired bullets from a standard infantry rifle at a distance of 50 m through 200 ml of 100% hydrogen

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peroxide contained in an aluminum tube 4.5 cm in diameter and 15 cm long⁽¹⁾. Bellinger⁽²⁾ fired armor-piercing, tracer, and incendiary bullets from a 0.50 caliber machine gun at a distance of 100 yd through 1 qt of 90% hydrogen peroxide contained in aluminum. No explosions were obtained.

4. Sensitivity to Explosive Shock

Card-gap tests were conducted with 70% hydrogen peroxide by the Naval Air Rocket Test Station, Dover, New Jersey⁽¹⁾. Results of the tests indicated that the sample was insensitive to the hydrodynamic shock from 50 gm of tetryl at zero card gap at ambient temperature and at 71°C. Cap-in-pipe tests with 90% H₂O₂ indicate somewhat more energy is produced than when water is tested. The pipes bulged and occasionally opened somewhat but liquid hydrogen peroxide solution was present after the test⁽¹⁾.

The results of early German investigations into the effect of the explosive shock generated by caps and F1147 on hydrogen peroxide contained in tubes are given in the following table⁽¹⁾:

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SUMMARY OF EXPERIMENTAL EXPOSURE TO HYDROGEN PEROXIDE

Hydrogen Peroxide Conc., % wt	Description of Test	Initiation	Results
0		10 gm PETN	Tube split open.
90.2		10 gm PETN	Tube opened 10 cm. H ₂ O ₂ left.
94.8		10 gm PETN	Tube opened 10 cm. H ₂ O ₂ left.
100.0*	Aluminum tube 21/23, 27 cm long, buried in loose moist sand.	10 gm PETN No. 10 cap	Tube destroyed Tube opened 6 cm.
100.0		No. 10 cap	Tube split. H ₂ O ₂ left.
100.0		No. 8 cap	Tube split. H ₂ O ₂ left.
0	Aluminum tube 21/23 inside iron tube 23/25, iron caps on ends.	No. 8 cap	Tube swelled slightly.
100.0		No. 8 cap	Tube torn open. H ₂ O ₂ left.
100.0		10 gm PETN	Tube destroyed.
100.0	Aluminum tube 25 mm diameter, 27 cm long. Glass tube 16 mm dia., 9 cm long placed inside aluminum tube. Glass tube filled with stoichiometric mixture of H ₂ O ₂ and ethanol.	10 gm PETN in stoichiometric mixture tube	Stoichiometric mixture detonated. Lower part of aluminum tube containing 100% H ₂ O ₂ left intact.
100.0	Glass tube 26 mm dia., 50 cm long. Glass partition at 25 cm. Upper end filled with stoichiometric mixture. Lower end filled with 100% H ₂ O ₂ . Tried with and without external iron case.	10 gm PETN in stoichiometric mixture end of tube.	Stoichiometric mixture detonated. Lower part of tube containing 100% H ₂ O ₂ left intact.

* Tube not buried.

Although the preceding information clearly indicates that hydrogen peroxide is very insensitive to shock, it should be noted that propagating detonations can be initiated in the liquid phase with powerful booster charges and extreme conditions of confinement or in the gas phase when the concentration of hydrogen peroxide is more than approximately 35 mole % (See Section C).

B. EXPLOSIVE DECOMPOSITION CHARACTERISTICS

1. Vapor Phase Explosion Limits

The vapor-phase explosion limits of hydrogen peroxide have been measured over a wide range of temperatures, pressures, and concentrations by Monger and co-workers(7) and by Satterfield and co-workers(6)(9)(10)(11). The total data now cover the temperature range of approximately 130 to 390°F, the pressure range of approximately 0.2 to 1000 psia, and the concentration range of approximately 4 to 70 mole percent H_2O_2 in the vapor. In addition to the study of the effects of these variables on explosion limits, the effects of various ignition sources (spark, hot filament, catalytic and non-catalytic metal surfaces), various diluent gases (water vapor, oxygen, nitrogen, helium, and carbon dioxide), superheating and packing, have been reported.

Although some differences in the efficiencies of sparks and hot filaments as ignition sources have been noted, the differences are not considered to be significant. The introduction of catalytic materials at ambient temperature into hydrogen-peroxide vapor systems also appears to be an efficient ignition method, but non-catalytic metal surfaces produce erratic results particularly when they are at temperatures below 300°F.

The study of the effect of diluent gases on ignition limits(9) shows that water vapor, oxygen, nitrogen, and helium behave similarly, but carbon dioxide does have an inhibitory effect by comparison. The use of packing appears to inhibit the initiation of vapor-phase explosions; however, the range of conditions under which the experiments were conducted was very narrow and does not justify generalization.

In Monger's work the generated hydrogen peroxide vapors were in equilibrium with liquid 90% H_2O_2 . He found that his data correlate well according to the following relationship:

$$\ln(y^{1/2}P^{-3/4}) = B + C/T \quad (1)$$

where y = mole fraction of H_2O_2 in the vapor, P = total pressure, T = absolute temperature, and B and C are constants. Although this correlation has value, the fractional powers make it somewhat cumbersome to apply. From studying the data it has been found that an equally good correlation can be obtained by the following relationship:

$$\log(\bar{C}_{H_2O_2}) = B + C/T \quad (2)$$

where $\bar{C}_{H_2O_2}$ is the mass of H_2O_2 vapor per unit volume.

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The temperature dependence of explosion limits as expressed in the two correlating equations given above appears logical at first glance. This dependence is, however, imposed by the temperature-pressure-composition relationship inherent in the 90% H₂O₂ vapor-liquid equilibrium system and is not necessarily significant in defining the explosive limits of H₂O₂ vapor not in equilibrium with 90% liquid hydrogen peroxide.

In Satterfield's early work⁽⁸⁾⁽⁹⁾ the generated hydrogen peroxide vapors were also in equilibrium with liquid H₂O₂ solutions but the liquid was not of constant composition. In his later work⁽¹⁰⁾⁽¹¹⁾ the vapors were slightly superheated. Satterfield's ignition-limit data do not correlate well with either Equation (1) or (2) but they could not be expected to in view of the fact that different temperature-pressure-composition relationships are involved. Satterfield⁽¹¹⁾ has commented that in slightly superheated vapors an increase in temperature might be expected to lower the ignition limit but he found experimentally that variations in vapor temperatures by 20°C or so at a fixed pressure produced no noticeable effect on the limit.

In view of the apparent small influence of temperature on ignition limits as found by Satterfield and the fact that both investigators' data could not be correlated by Equation (1) or (2), a simple correlation of both Monger's and Satterfield's data in terms of only total pressure and mole fraction of H₂O₂ in the vapor has been attempted. These data are presented in Figure 1. Monger's data⁽⁷⁾ are shown by dots and crosses, the dots denoting non-explosive conditions and the crosses denoting explosive conditions. Satterfield's data⁽⁸⁾⁽¹⁰⁾ are given by open circles and denote the boundary between explosive and non-explosive regions. It can be readily seen that a simple, single boundary line can not be defined by the data without assuming the experimental data have very low precision. It is obvious, however, that the data of Monger and Satterfield agree quite well at pressure below about 45 psia but disagree considerably at higher pressures, apparently defining two distinctly different limits. Monger's data at elevated pressures show considerable scatter, but this is understandable in view of the method employed in arriving at the vapor-phase composition (calculated from extrapolated vapor-liquid equilibrium data, temperature measurements, pressure measurements, and liquid phase composition). Thus, errors could arise from the extrapolation, the measurements, or by neglecting vapor-phase decomposition. In any case, Satterfield's data indicate little or no dependence of the limiting H₂O₂ vapor concentration on pressure above 45 psia while Monger's data indicate quite clearly that the limiting vapor-phase concentration decreases as pressure increases.

No reference has been found that would directly suggest that hydrogen peroxide vapor may have multiple explosive limits; however, multiple limits are known to exist in a number of explosive systems. For example, F₂-O₂ gas mixtures are known to have three limits as shown qualitatively below:

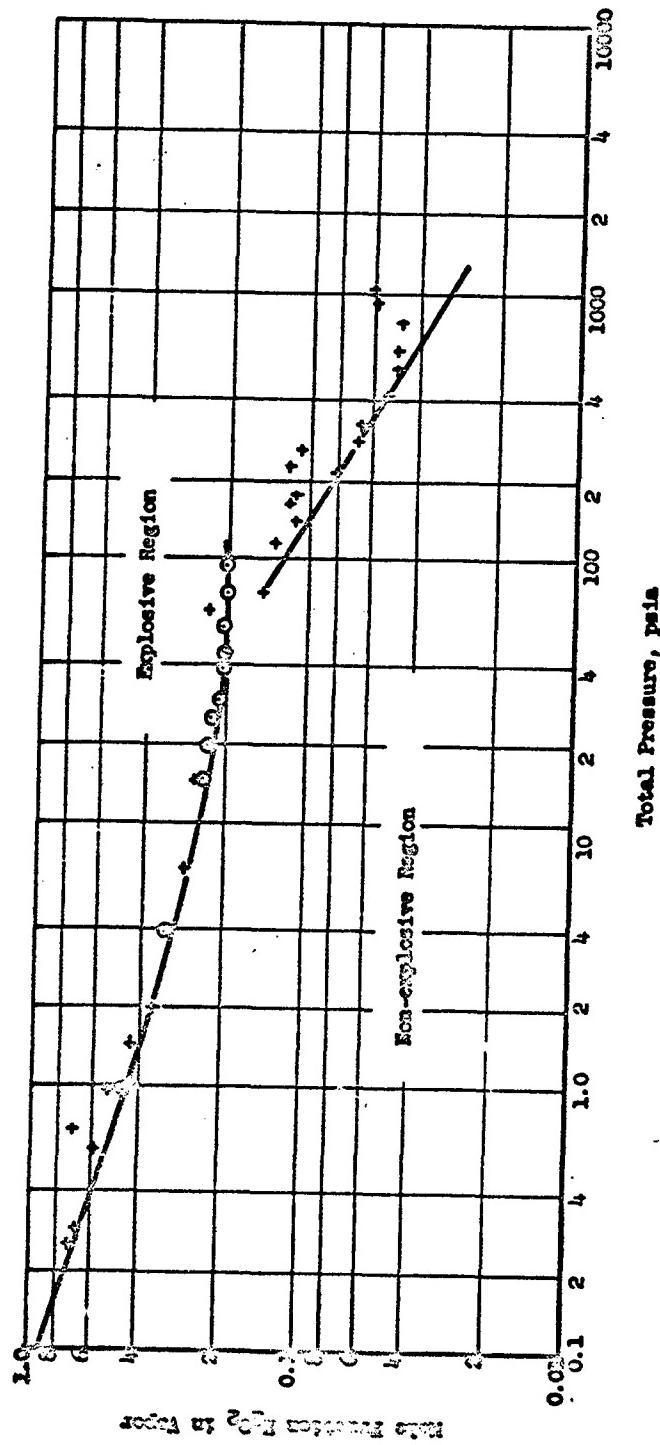
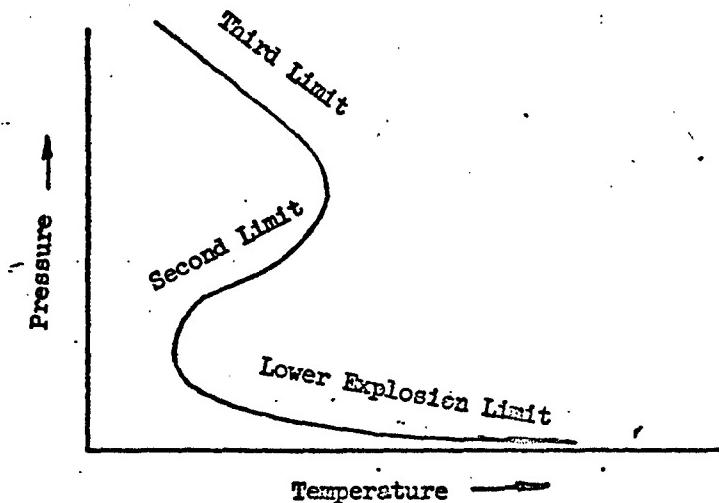


Figure 1. Explosion Limits of H_2O_2 Vapor

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Because hydrogen peroxide vapor decomposition and H₂-O₂ vapor reaction would be likely to yield similar intermediate species, some resemblance to each other could be anticipated (such as multiple explosion limits).

Although Figure 1 does not adequately define all the conditions for avoiding vapor-phase explosions with H₂O₂, it does appear to provide a more general guide than any other representation known. It is readily apparent, however, that additional data will be required before the explosive characteristics of hydrogen peroxide vapor can be fully defined or understood (See Section IV,D,3,c, of this report for an interpretation of these data based upon the subscale catalyst tests).

Globus(12) recently studied the explosive characteristics of 93% wt hydrogen peroxide. He found that upon heating the material in Pyrex at atmospheric pressures that a very rapid, but not violent, vapor-phase reaction occurred spontaneously when a temperature of 210°F was reached (~ 74 mole % H₂O₂ in the vapor phase). These conditions are well within the explosive region defined by Figure 1, and the occurrence of an explosion is therefore understandable. Prepressurizing the sample to 15 psig with nitrogen (at ambient temperature) and sealing permitted heating to about 300°F (one sample exploded at 293°F while another reached 301°F, was held at that temperature for 5 min and cooled down with only minor decomposition occurring). Extension of these studies to higher levels of prepressurization in 3½ stainless-steel bombs indicated that the pressurization had an inhibitory effect on the explosive reaction. Prepressurization to 500 psig with nitrogen (at ambient temperature) allowed 93% hydrogen peroxide to be heated to 300°F and maintained at that temperature for 15 min before a pressure peak occurred. Prepressurization to

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1000 psig allowed the material to be held 42 min at 300°F before a pressure peak occurred, and 1500 psig pressurization allowed holding at 300°F for 84 min before a pressure excursion was noted.

Globus' results, plus those previously cited from the sub-scale catalyst task, aid in further defining explosive limits of hydrogen peroxide vapor; they indicate that the missing parameter in Figure 1 is time. Also not defined is the function of explosive property on system geometry. Both of these parameters have been shown to affect the rate of decomposition of peroxide vapor.

2. Hydrogen Peroxide-Water-Organic Fractions

Shell Development Company⁽¹⁾ has published a very comprehensive summary of research data on the safety limitation of H₂O₂-H₂O-organic compound systems. This summary is not reproduced here because of its length and the relatively small importance of such systems in the evaluation of high-strength hydrogen peroxide for rocket use. However, the summary should be consulted if such systems are of interest for some other reason.

Shanley and Perrin⁽¹³⁾ studied the relationship between thermal properties and explosive properties for mixtures containing hydrogen peroxide, water, and soluble organic compounds. It has been known for some time that certain mixtures of this kind are explosive. In the study, it was found that sensitivity to initiation is about the same for all mixtures having the same heat of reaction. This relationship was demonstrated for five different organic constituents and for three methods of initiation. The findings provide an easy basis for predicting the likely range of explosive compositions of untested mixtures containing H₂O₂. This report should also be consulted where such systems are of interest.

3. Explosive Strength of Hydrogen Peroxide

Shell Development Company reports⁽¹⁾ that the Germans performed explosive strength tests with hydrogen peroxide-water systems (40 to 100% H₂O₂) using the German Land Block test. An expansion in the Land block (compared to water as a blank) for various concentrations of hydrogen peroxide is given in the following table:

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EXPLOSIVE STRENGTH OF H₂O₂ - H₂O MIXTURES BASED ON TIN-DIOL EXPANSION

<u>% wt H₂O₂</u>	<u>Expansion*, cc/g</u>
100	11.3
98	9.8
90	6.3
80	4.3
70	3.2
60	2.5
40	1.7

* Compared to water as a blank.

The explosive strength of hydrogen peroxide is not very high when compared with mixtures containing organic compounds. A calculation by the U.S. Bureau of Mines indicates that the explosive energy release for the complete decomposition of 90% H₂O₂ to water and oxygen would be about 39% of the energy released from an equal weight of TNT(1).

C. DETONATION CHARACTERISTICS

1. Liquid Hydrogen Peroxide

Shell Development Company reports that the Germans investigated the detonation velocity of various concentrations of hydrogen peroxide using both the Dautriche and an optical method. A few other quantitative results are given by Medard(14). The data are given in the following table:

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DETONATION VELOCITY OF HYDROGEN PEROXIDE-WATER MIXTURES

Hydrogen Peroxide Conc., % v	Test Method	Tube Material	Initiation	Velocity, m/sec
99.7	Optical	25/30 V2A Stainless Steel	30 gm FETN	6500
99.7	Optical	25/30 V2A Stainless Steel	30 gm FETN	Failed to Propagate
99.7	Optical	25/30 V2A Stainless Steel	30 gm FETN	Failed to Propagate
100.0	Dau triche	15/20 Glass	?	No detonation
100.0	Dau triche	15/25 V2A	30 gm FETN	No detonation
100.0	Dau triche	25/30 V2A	30 gm FETN	6000 to 7000
Various From 100 to 95	?	25/30 V2A	30 gm FETN	6000 to 7000
Various Below 95	?	25/30 V2A	30 gm FETN	No detonation
92	-	3 $\frac{1}{4}$ /37 Steel	50 gm Penthrite	Detonated 10 cm
94	-	3 $\frac{1}{4}$ /37 Steel	50 gm Penthrite	Detonated total length of tube, 25 cm
99.6	-	3 $\frac{1}{4}$ /37 Steel	50 gm Penthrite	Detonated total length of tube, 25 cm
99.6	-	Thin Walled Aluminum	?	No detonation

It is obvious from the preceding information that the $H_2O_2-H_2O$ system can detonate with a velocity of 6000 to 7000 m/sec when the hydrogen peroxide concentration is 95% or greater. Below about 95% H_2O_2 it appears extremely difficult, if possible at all, to obtain a propagating detonation at ambient temperatures.

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More recent measurements by Eloom and Brunsfield(3) confirm the results presented thus far. Their data indicate that 55% hydrogen peroxide can be detonated at ambient temperature in a 2 or 4 ft length of 1-in.-ID (0.17 in. wall thickness) pipe using 20 gm of tetryl as the initiator. A 10-gram charge of tetryl was insufficient to obtain a propagating detonation. Propagation could not be obtained in smaller-diameter pipes (0.75 or 0.50 in.) even with 40 gm of tetryl as the initiator.

It can be deduced that the failure radius for this system is of the order of 1.0 cm as contrasted with about 0.2 cm for the mixtures with organic compounds. Assuming that the activation energy for the explosive reaction is of the order of a few kcal, a reaction zone length of about 0.5 cm can be estimated. This high a reaction-zone length is in accord with the relative insensitivity of the system(1).

Assuming a reaction-zone length of the order of 0.5 cm, it is quite possible that a region exists at high hydrogen-peroxide concentrations in a system containing an organic compound where a standard impact test will give a negative result but where the system is still potentially capable of a high-order detonation(1).

An abstract of a report which was not available in original form(15) indicates that detonation can be obtained at concentrations as low as 86% under heavy confinement and that the detonation velocity is of the order of 4500 m/sec.

2. Hydrogen Peroxide Vapor

Monger et. al.(16) have conducted experiments at 2.90, 6.77, and 14.7 psia to obtain information concerning the detonation characteristics of hydrogen peroxide vapor. Within the experimental conditions employed, no detonations were observed at 2.90 and 6.77 psia. At atmospheric pressure, detonations with a velocity of 6700 ft/sec were observed in vapor with a composition of 35 mole percent hydrogen peroxide. Experiments at higher concentrations were attempted many times with several equipment modifications but were unsuccessful because of spontaneous decomposition or premature ignition of the vapor. The detonation tube itself was an 8-ft length of 2-in. Schedule 80 6063-T6 aluminum pipe.

3. Hydrogen Peroxide-Water-organic Systems

The detonation characteristics of these systems are described in a comprehensive summary of research data on safety limitation(1). This source should be consulted when considering hydrogen peroxide containing organic compounds.

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D. IGNITION AND BURNING CHARACTERISTICS

1. Autoignition

(u) Very little definitive data are available on the autoignition of concentrated hydrogen-peroxide solutions. The data that are available clearly indicate that ignition takes place in the vapor phase and is propagated back to the liquid surface. Undoubtedly, the ignition is caused by heterogeneous decomposition on the container walls. Becco(17) reports that autoignition occurs when heating 90% hydrogen peroxide in open stainless steel beakers and the bulk temperature reaches 275°F. Globus(12) reports that autoignition occurs when heating 98% hydrogen peroxide in Pyrex and the bulk temperature reaches 288°F. See also Section B,1 for information on vapor-phase ignition and explosion characteristics.

2. Ignition

(c) Rocketdyne(5)(6) reports that the ignition of 90% H₂O₂ at atmospheric pressure could not be obtained with a hot (1600 to 1800°F) nichrome resistance wire placed in either the vapor or liquid phase when the bulk temperature was below 230°F. Above this temperature (at 1 atm) ignition was rapid when the source was placed in the vapor phase just above the liquid surface. Ignition became increasingly difficult as the source was moved from the surface. Ignition was not obtained when the source was immersed in the liquid even when the bulk liquid temperature was above 230°F. The situation was similar at 30 psig; however, the minimum bulk liquid temperature had to be at least 242°F to obtain ignition. At 100 psig ignition failed even at bulk liquid temperatures of 330°F, probably because the vapor was decomposing on the container walls or diffusing into the atmosphere so fast that the vapor-phase composition was outside the ignition limits - see also Section B,1.

(u) Marshall(18) has determined the quenching distances and minimum spark-ignition energies of H₂O₂ + H₂O vapor mixtures containing between 35 and 50 mole % H₂O₂ and at pressures between 25 and 200 mm Hg. The vapor temperature was in each case 9°C above its condensation temperature. The method used was that of passing capacitance sparks between electrodes fitted with parallel flanges at their ends, the electrode separation being variable. A flow apparatus was used because of the readiness with which H₂O₂ decomposes on surfaces.

(u) The quenching distances varied between 0.51 and 1.63 cm and the ignition energies between 0.53 and 25.5 millijoules, decreasing with increasing H₂O₂ content and pressure. All the results fitted the equation

$$E_{\min} = 3.84 d_q^{3.04}$$

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where E_{ign} is the ignition energy (in mJ) and d_q is the quenching distance (in cm). He discussed the results in terms of other properties of the mixtures.

3. Flame Speed

(c) Baumgartner et al. (19) studied the flame speed of decomposing hydrogen peroxide vapor near the flammable limit in a 2-in.-dia tube. They found flame speeds as high as 70 ft/sec but found no correlation between flame speed and hydrogen-peroxide concentration.

(u) Note that flame velocity is not the burning velocity which is defined as the velocity of the reaction zone front with respect to the unburned gas. The burning velocity is characteristic of the gas, concentration, temperature, and pressure; the flame velocity is, in addition, dependent on the apparatus used.

4. Burning Velocity

(c) The burning velocity of 90% hydrogen peroxide at 0 and 30 psig has been measured in 8-mm-ID tubes by Rocketdyne (6). Such tubes were selected because the literature appeared to indicate that wall effects were negligible in a container of that size. Ignition was accomplished with a nichrome resistance wire heated to a bright red color (1600 to 1800°F). Ignition could not be obtained in either the vapor or liquid phase when the bulk liquid temperature was below 230°F at 0 psig or below 242°F at 30 psig. Ignition could not be accomplished at 100 psig even at a bulk liquid temperature of 330°F.

(c) The burning rates obtained are summarized below and in Figure 2.

BURNING RATE OF 90% HYDROGEN PEROXIDE

Pressure, psig	Average Temperature, °F	Burning Rate, cm/sec
0	237.7	0.0115
0	245.9	0.0126
0	240.4	0.0134
0	245.8	0.0136
0	257.8	0.0156
30	244.5	0.0167
30	254.0	0.0246
30	271.0	0.0294
30	263.0	0.0330
30	275.5	0.0363
30	281.5	0.0373
30	292.0	0.0488
30	295.5	0.0596

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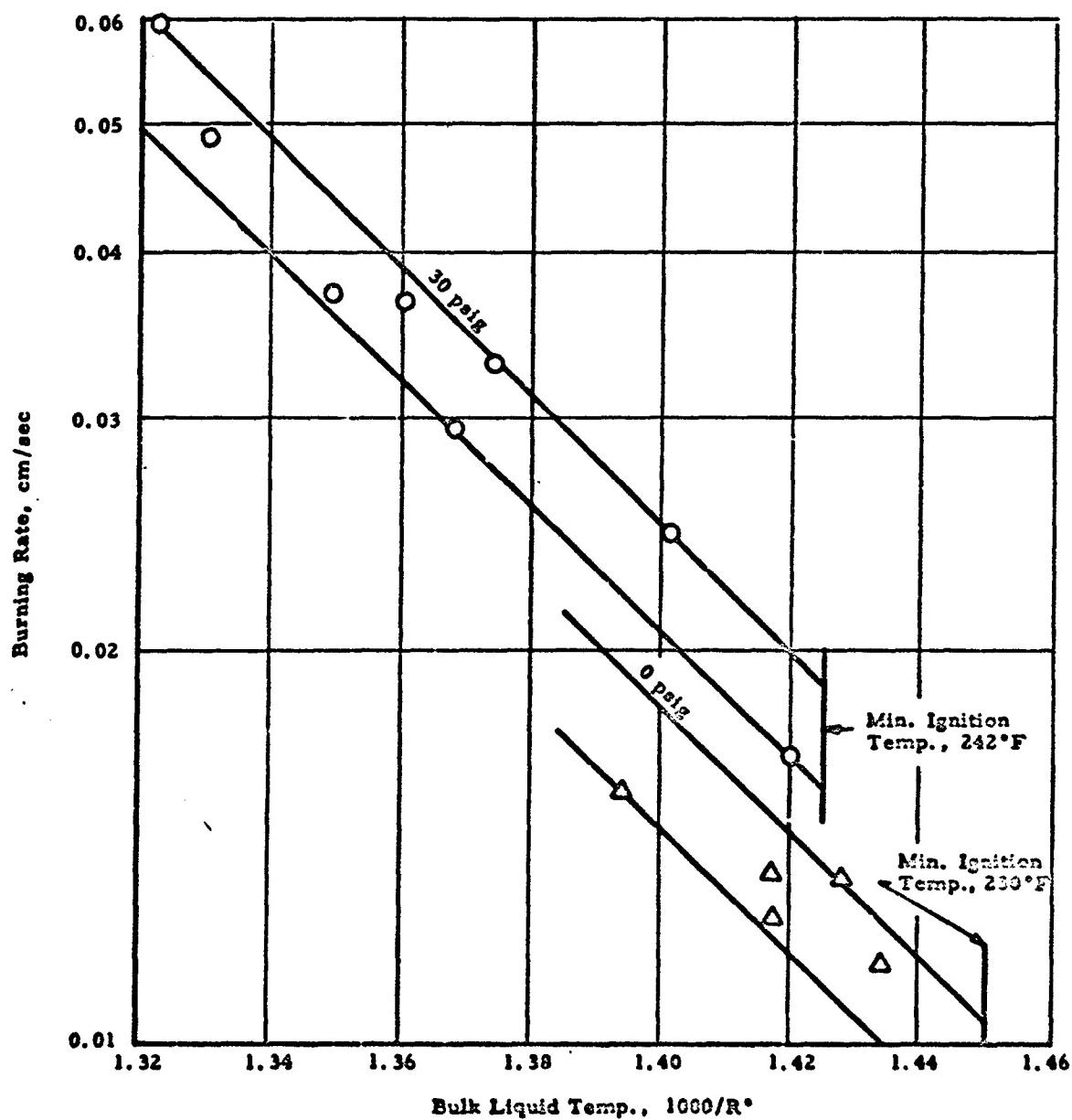


Figure 2. Burning Rates of 90% wt Hydrogen Peroxide (u)

Kehat⁽²⁰⁾ has summarized the burning-velocity data on hydrogen-peroxide decomposition flames. His evaluation of the data indicates that there is no dependence of the burning velocity on the vapor velocity. He reached the following conclusions:

- a. Burning velocities of H₂O₂ vapor mixtures are well correlated by the product of the square of the burning velocity and the pressure against the reciprocal flame temperature as by more complicated relations.
- b. The reaction in the flame is approximately first order with an apparent activation energy of 35 kcal/mole.
- c. Burning velocity is not a sensitive enough parameter for a study of the final points of reaction mechanism in the flame.
- d. Useful correlations of burning velocities of H₂O₂ vapor mixtures and liquid solutions, of burning velocity and quenching distance, and of approximate flashback and blowoff limits were obtained.

E. PHYSIOLOGICAL EFFECTS AND FIRST AID

1. Effect on the Senses

Schumb et al.⁽²¹⁾ has described the effects of hydrogen peroxide on the senses. They state that hydrogen peroxide, like water, has no apparent flavor; however, it does induce a sensation of astringency, sometimes described as "metallic". An effervescence similar to that of soda water occurs as the hydrogen peroxide decomposes, giving a prickling sensation. At high concentrations all these effects in the mouth are heightened to the point of painfulness, to say nothing of the hazard of burns.

They further state that it is difficult to characterize the smell of hydrogen peroxide. In fact, it is questionable whether or not it affects the olfactory cells or merely stimulates the general nerves of the nasal mucous membrane. Concentrated hydrogen peroxide manifests little odor unless occasion is deliberately taken to inhale near the surface of the liquid or unless it is spilled extensively. The sensation perceived is then reminiscent of ozone or of the halogens. If circumstances arise to cause the dispersion of considerable hydrogen peroxide in the air, as in a mist, considerable irritation shortly ensues. Prolonged breathing of such an atmosphere induces gnawing such as is encountered with ammonia or sulfur dioxide and is accompanied by a sharp, burning sensation in the nasal passages.

2. Skin

The effect of 90% hydrogen peroxide on human skin from different parts of the hands has been described on the basis of a toxicological study conducted at Huntsville Arsenal⁽²¹⁾. A thin smear of concentrated

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hydrogen peroxide applied to skin where the keratin is thick and nerve endings abundant (e.g., palms and fingers) causes strong reddening and formation of opaque white patches. Under the fingernails this is reported to be extremely painful. The whiteness is apparently brought about by refraction in the gas formed by the decomposition under the first layer of skin. Longer applications may cause reddening and appearance of papules possibly followed by thickening. On other skin areas where the keratin is thinner, irritation occurs, but with less itching and the whitening is confined to a few areas at the base of hairs. There is no evidence of penetration deeper than the first layer of skin (stratum corneum) and all these effects disappear without trace.

First aid for skin contact (22)(23) includes immediate flushing with water (speed is more important than the length of time the area is flushed) and the application of clean compresses saturated with a solution of 1 part potassium permanganate in 5000 parts of water. The compresses should be left on about 5 min and resaturated with the permanganate solution as necessary. If redness or blistering is evident, a physician should be consulted.

3. Eyes (21)(22)(23)

Exposure of the eyes to splashes from concentrated hydrogen peroxide may cause severe damage including ulceration of the cornea, with resulting blindness. It should be noted that there may be a delayed appearance of damage to the eyes and corneal ulceration may appear even a week or more after exposure. A vaporizing leak will sting slightly and cause watering of the eyes but no real damage. Tests with rabbits in which small amounts of 90% H₂O₂ (near 1 cm³) were applied to the cornea produced effects very closely resembling those seen in the skin. The effects disappeared without residual injury in a few days. Larger amounts (near 3 cm³) apparently produced permanent blindness.

First aid for eye exposure, even to minute quantities of concentrated hydrogen peroxide, calls for immediate flushing with water and this flushing should continue for 15 min. This may be followed by rinsing with a 5% solution of boric acid. For any case of eye exposure to the concentrated liquid, an eye specialist should be consulted.

4. Inhalation

The Army Medical Center, Medical Division, has performed tests to determine the effects of air saturated with 5% H₂O₂ vapors at 75 to 80°F for 8-hr periods on rats(4). The test animals were observed for 14 days following the exposure. No rats died and there were no symptoms other than excitement at the beginning of the exposure. Thereafter the rats remained calm and appeared normal. The Medical Division concluded that the acute inhalation hazard of air saturated with 90% H₂O₂ vapors (at ambient temperatures) is relatively insignificant. The inhalation of larger quantities of

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hydrogen peroxide vapor, however, may cause extreme irritation and inflammation in the nose and throat and, if prolonged, can produce swelling or accumulation of fluid in the lungs. The threshold limit for hydrogen peroxide vapor was set at 1 ppm but has recently been raised to 7 ppm(24).

First aid for inhalation exposure(22) merely calls for removing the person from the contaminated area and supplying plenty of fresh air.

5. Ingestion (Oral Intake)

The ingestion of dilute hydrogen peroxide has been found to cause no adverse effects(21). Concentrated solutions can, however, cause bleaching and slight swellings of the lips and mouth(22) and swallowing may cause bleeding from the lining of the stomach(21)(22). Additionally, swallowing presents the danger of rupture from violent gas evolution(21).

First aid for ingestion(22)(23) includes encouraging vomiting and eructation (belching) and giving lukewarm water or warm milk. If the mouth is burnt, the pain and swelling can be alleviated somewhat by sucking ice. Refer further treatment to a physician.

F. FIRE HAZARDS AND FIRE CONTROL

Concentrated liquid hydrogen peroxide is not flammable in the usual sense; however, once ignited, it will "burn" rapidly as a continuous, hot, nearly invisible vapor-decomposition flame close to the surface of the liquid. The high temperature of this flame front (~1350°F for 90% H₂O₂ and ~1700°F for 98% H₂O₂) can produce considerable fire damage itself but also serves to ignite combustibles in spill areas. Combustible materials (including ordinary clothing) which are wetted by concentrated hydrogen peroxide can be ignited very readily. The vapors above 90% H₂O₂ can be ignited by an external source when the liquid temperature is near 230°F(5)(6) and they can autoignite at temperatures near 277°F(17). 98% H₂O₂ can auto-ignite at 203°F(12). Once a hydrogen peroxide decomposition flame is established, it will continue until the liquid is consumed or until diluted or cooled.

The best means of controlling hydrogen peroxide fires is through the application of water. Chemical fire extinguishers should not be used.

G. SUMMARY CONC(22)(23)

The rules and precautions that are recommended for the safe handling and use of concentrated hydrogen peroxide were listed in Appendix IV. In addition, any handling operations should be performed by two or more persons. The stationing of one man near a water source so he can readily

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cleanse and wash away any spillage is recommended. Spillage (especially on the body or clothing) must be flushed at once with a large quantity of water. Also, clean equipment such as pipes, lines, and valves and flush with water before disassembly or repair. Never attempt to repair equipment while it is in operation. If pipes or lines are to be removed and flanges opened, first lead out a water hose, then loosen the lower bolts and wash away any drippage. After repair, equipment must be repassivated.

E. SAFETY EQUIPMENT

1. Protective Clothing (22)(25)

Typical light-weight clothing is described in the following table:

TYPICAL LIGHT-WEIGHT PROTECTIVE CLOTHING FOR Radio SERVICE

<u>Item</u>	<u>Description</u>	<u>Source</u>
Trousers	Dacron fabric, no pockets or cuffs, polystyrene buttons	Worklon, Inc. New York 1, New York
	Dynel fabric	Mine Safety Appliance Co.
	100% Dynel Chem-Weave, med. wt.	Chem-Wear Inc., Darien, Conn.
Shirts	Dacron fabric, polystyrene buttons	Worklon, Inc.
	Dynel fabric	Mine Safety Appliance Co.
	100% Dynel Chem-Weave, med. wt.	Chem-Wear, Inc.
Caps	Dacron fabric, baseball type with removable sunshade for neck	Worklon, Inc.
	Dynel fabric	Mine Safety Appliance Co. Chem-Wear Inc.
Shorts	Dacron fabric	Worklon, Inc. Carmi-Airbreath Corporation, Carmi, Ill. Manhattan Shirt Company, New York, N. Y.

ITEMS OF PERSONAL PROTECTIVE EQUIPMENT USED IN FIRE SERVICE (cont'd.)

<u>Item</u>	<u>Description</u>	<u>Source</u>
Undershirts	Dacron	Almac Knitting Mills, New York, N.Y. (Spec. lot, min. order 10 doz.)
	Dacron-cotton (can be ignited if soiled)	Carmi-Ainsbrooke Corporation
Socks	Knit dacron, no elastic, white	Holston Mfg. Co., Knoxville, Tennessee
	Dynel fabric	Numerous commercial sources
Belts	Vinyl plastic with plastic buckle	Numerous commercial sources
Goggles	Willson Monogoggle, No. 93 AV large nose, clear	Willson Products, Inc., Reading, Pa.
	SAF-I-CHEM, Model 293607, Series 29, clear lens	U.S. Safety Service Co., Kansas City, Mo.
Gloves	Sureseal, gauntlet, vinyl or Neoprene, No. 116 (light wt. for lab use) or No. 155 (med. wt. for work use)	Surety Rubber Co., Carrollton, Ohio
Face Shield	Sellstrom, No. 324, clear	Watson Co., Buffalo, N.Y.
Hoods	8 mil vinyl plastic with window of methacrylate, detachable head band	Milburn Company Detroit 7, Michigan
Shoes	6-in. Neoprene coated, No. 990, steel toe	Childs & Co., Inc., Iron Age Div., Pittsburgh 12, Pa.
Rubbers	Full, Neoprene with tongue	Numerous commercial sources
Boots	Neoprene, knee length	Numerous commercial sources
Booties	Vinyl plastic, light weight, disposable, double sole	Mine Safety Appliance Co.

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TYPICAL INDOOR STANDBY CLOTHING FOR H₂O₂ SERVICE (cont'd.)

<u>Item</u>	<u>Description</u>	<u>Source</u>
Aprons	8 mil vinyl plastic, surgeon's type, extra long, overlapping in back with front ties	Milburn Co.
Impermeable Jacket	Fiberthin Raynster, Neoprene coated Nylon, MBS-107	U.S. Rubber Co., Washington, Ind.
Impermeable Overalls	Fiberthin Raynster, MBO-107	U.S. Rubber Co.

For normal handling and transfer operation, the permeable clothing offers adequate protection when worn with goggles, gloves, and recommended footwear. Impermeable clothing, however, must be worn in emergencies such as when leaking and splashing of hydrogen peroxide is likely to be encountered.

Winter-weight protective clothing for outdoor service is described in the following table.

TYPICAL OUTDOOR WINTER-WEIGHT PROTECTIVE CLOTHING FOR H₂O₂ SERVICE

<u>Item</u>	<u>Description</u>	<u>Source</u>
Trousers	55% Dacron-45% wool, no pockets or cuffs	Worklon, Inc., New York 1, N.Y.
Shirts	55% Dacron-45% wool, sport-type, polystyrene buttons	Worklon, Inc.
Caps, Jackets, and Pants	100% Dacron pile lining and outer material	G.W. Berg Co., Berg Fabric Div., Delavan, Wis.
Boots	Neoprene, insulated. Similar to U.S. Army all-rubber, insulated combat boots	Hood Rubber Co., Watertown, Mass.

For emergency use, a impermeable vinyl apron or coverall and hood can be worn over the pile-lined clothing.

2. Safety Showers (22)

Deluge-type safety showers must be available in areas where hydrogen peroxide is stored, handled, or used. When it is impracticable to

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to install permanent equipment, a temporary shower can be improvised from a water hose and suitable nozzle or shower head. These showers should be tested prior to beginning operations each day.

3. Respiratory Protection(22)

When heavy hydrogen peroxide vapor, mists, or aerosols are encountered, gas masks can be worn to protect the respiratory system. Only masks approved for this purpose by the U.S. Bureau of Mines should be used and the manufacturers instructions must be carefully followed.

4. DISPOSAL

The most widely accepted method of disposing of waste hydrogen peroxide is dilution and dumping. Concentrated hydrogen peroxide should be diluted as far as practical but with at least twice its volume of water and preferably with ten times its volume. Once diluted the peroxide can be dumped into an open body of water, into an open drainage ditch that is cleared of all combustibles (and preferably containing water), or into a sewer or closed drain (providing combustible materials are not also dumped into the same drain and that a large amount of water is added during and after the dumping process).

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~~EXHIBIT 3~~

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